THE EPIDEMIOLOGY OF INJURIES IN COMPETITIVE ADOLESCENT SWIMMERS ATTENDING A JOHANNESBURG SWIM SQUAD

A DISSERTATION PREPARED BY INNEKE SCORGIE (SCRINN001) IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE MASTER OF PHILOSOPHY DEGREE IN SPORTS PHYSIOTHERAPY (MPHIL SPORTS PHYSIOTHERAPY) FROM THE UNIVERSITY OF CAPE TOWN

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DECLARATION

I, Inneke Scorgie (SCRINN001), hereby declare that the work on which this dissertation is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other university.

Signed by candidate

(Signature)

14.02.2016

(Date)

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AE	Athlete exposure
Back	Backstroke
BMI	Body mass index
Breast	Breaststroke
CI	Confidence interval
Fly	Butterfly stroke
GIRD	Glenohumeral rotation deficit
h	Hour
HHD	Hand-held dynamometer
IM	Individual medley stroke
kg	Kilogram
km	Kilometre
m	Metre
ROM	Range of movement
RPE	Rate of perceived exertion
SD	Standard deviation
TAM	Total arc of motion
TAMD	Total arc of motion deficit
wk	Week
y	Year

GLOSSARY OF TERMS

Term	Definition
Acute injury	Trauma resulting from a specific and identifiable event[1–3].
Athletic exposure (AE)	One athlete partaking in one coach directed practice session or game[1,4].
Body mass index (BMI)	The weight of a person in kilograms (kg) divided by the square height of that person in meters (m). An indicator of whether an individual is underweight or overweight[5].
Competitive swimming	The participation in professional swimming training programmes and specific conditioning in order to optimise performance[6].
Denominator	The function with which injuries are expressed as a rate using either total number of athletic exposures, total number of participating athletes or total number of matches or training sessions[7]
Drag force	Water exerting a force against the body that inhibits forward propulsion[8,9].
Dry-land training	Specific strengthening or resistance program performed out of the water, aimed at improving swimming performance[10].
Extrinsic risk factor	External / environmental factors that have an impact on the athlete while he / she is participating in sport, such as training methods or equipment[11,12].
Flip-turn	A means of changing swimming direction by rapidly flipping the legs and body over the head, incorporating body rotation and pushing off the wall with both feet[9].
Flutter kick/dolphin kick	A type of kick often used in the butterfly stroke where both legs kick simultaneously, imitating a dolphin's fin. It is often used by freestyle swimmers whilst kicking off the wall[9].
Freestyle	Alternate arm strokes using body roll to aid propulsion with one arm while simultaneously aiding recovery of the other. An alternate 'flutter' leg kick is normally used[13].
Glenohumeral internal rotation deficit	The loss of glenohumeral internal rotation range of motion in the dominant versus the non-dominant arm[14–16].
Hand-paddles	A device covering the surface of the hand aimed at reducing grip on the water and improving forearm strength in forward propulsion[9].
Health literacy	An individual's ability to seek, understand and utilise health information[17].

Term	Definition
Index injury	First injury occurring within the study period[18].
Injury location	Distribution of injuries by body part/ anatomical location[19].
Injury incidence rate	Calculated as the number of injuries per 1 000 player hours or AE's [(Σ injuries/Σ AE) × 1 000][3,12].
Injury nature	Refers to the location, type, side injured and recurrence of the injury[3].
Injury type	Classified as an injury occurring in bone, joint and ligament, muscle and tendon, central /peripheral nervous system or skin lesions[2,3].
Intrinsic risk factor	Specific biologic and psychosocial characteristics predisposing an athlete to the outcome of injury[12].
Modifiable risk factor	Modifiable risk factors refer to those that can be altered by injury prevention strategies to reduce injury rates such as strength, balance and flexibility[12].
Non-modifiable risk factor	Cannot be altered, may affect the relation between modifiable risk factors and injury such as gender and age[12].
Overload	Sudden increases in training load that exceed normal training volumes[20].
Overuse injury	Gradual-onset injury caused by repeated micro-trauma without a single, identifiable event responsible for the injury[1–3].
Pull-buoy	A specially shaped float designed to sit between a swimmer's legs, providing sufficient buoyancy to focus solely on arm stroke[9].
Recurrent injury	Type of subsequent injury (same location and same type as index injury)[17].
Risk factor	Any factor that may increase the potential for injury[11].
Sport's injury	Any injury related to the practice of a sport, often resulting from the overuse and stretching of muscles, tendons and ligaments[5].
Sports specialisation	The intense, year-round training of a single sport with the exclusion of other sports[21].
Swimmer's shoulder	A collective term used for a variety of shoulder pathologies in swimmers[22].
Swimming drills	Exercises performed in the water to practice aspects of swimming strokes to ultimately improve stroke technique. Drills commonly form part of the warm-up in a swimming[9].

Term	Definition
Time-loss	Number of practice sessions / competitions that are modified or missed as a result of injury[2,3].
Time-trial	A maximal-effort race against the clock to establish how fast one can cover a particular distance, forming an important part of most training programmes to provide feedback about the value and effects of training[5].
Total arc of motion (TAM)	Total arc of motion is measured by adding glenohumeral internal and external rotation together[14,16,23].
Training session	Team training that involved physical activity under the supervision of the coaching staff[2,24].
Warm-up	Partaking in low intensity physical activity prior to the main event for the purpose of improving performance. Warm-up is aimed at improving blood flow whilst increasing heart rate, respiratory rate and temperature without causing fatigue[25].

ABSTRACT

Background

Swimming is a popular competitive and recreational sport performed worldwide by all generations. Although swimming is associated with many positive health benefits, swimmers are at risk of developing musculoskeletal injuries. In particular, competitive swimmers may be at increased risk of injury, due to regular participation in demanding training regimes. Adolescent swimmers may be at increased risk of injury due to physiological and biological vulnerability associated with growth and development. However, there is a lack of evidence regarding the epidemiology of injuries in competitive adolescent swimmers.

Aim

The aim of this study was to determine the relationship between injury incidence and potential risk factors in adolescent swimmers over a 24-week period.

Specific Objectives

(a) To describe the demographic and training characteristics of competitive adolescent swimmers; (b) to establish the incidence and nature of self-reported swimming-related injuries in competitive adolescent swimmers; (c) to determine if any specific intrinsic factors and extrinsic factors were associated with increased risk of injury in competitive adolescent swimmers.

Methods

Twenty three competitive adolescent swimmers aged 12 to 18 years were recruited for the study. Swimmers attended a study information session and parents/legal guardians were emailed information sheets and informed consent forms. All participants brought signed informed consent forms from parents/legal guardians to the baseline data collection session. At baseline testing participants signed their own informed assent forms and completed the baseline questionnaire, anthropometry measurements, glenohumeral range of movement measurements, the Beighton score and glenohumeral and knee muscle strength measurements. Participants were advised on how to complete the electronic injury report and training questionnaire. A familiarisation trial-run of the survey was completed in the week following baseline testing. Formal data collection commenced two weeks after baseline testing. Participants were required to submit the injury report and training questionnaire on a weekly basis for the 24-week study period.

Results

The mean age for commencement of swimming training in both the injured and uninjured groups was approximately 7.5 years. The injured group had significantly decreased subscapularis muscle strength ($p = 0.02$) and significantly higher average training session distances ($p = 0.04$), compared to the uninjured group. Fourteen participants (60%) sustained injuries during the 24-week study period. The injury rate was 22.4 per 1 000 athletic exposures (AE's). Sixty injuries were sustained in total; 16 were index, and 44 were recurrent injuries. The most common injury location was the knee joint (n = 20). The only factors associated with increased injury risk in this study were previous injury history (OR: 7.50; 95% CIs 1.02-55.00) and reduced percentage of time in breaststroke training (OR: 12.83; 95% CIs: 1.69-97.19). Few swimming training sessions were modified or changed due to injury, and the majority of injuries did not receive any treatment.

Conclusion

The injury incidence of adolescent competitive swimmers attending a Johannesburg-based swim squad is high. In addition, the high number of recurrent injuries, the minimal adaptation of training loads in response to injury, and the low access to appropriate treatment suggest a lack of knowledge or poor practices regarding swimming-related injuries. Pre-season screening, specific to swimming, could assist in identifying weakness and potential risk factors for injury in this vulnerable age-group. Improving health literacy with education in swimmers, coaches and parents could reduce future injury incidence rates. Therefore, further research is needed regarding injury incidence, risk factors and training profiles of this population. Moreover, consensus regarding injury definitions and training loads in adolescent swimmers is needed to standardise reporting and to facilitate further research in this field.

CHAPTER 1: INTRODUCTION AND SCOPE OF THE THESIS

1.1 INTRODUCTION

Swimming is a popular sport that combines elements of both cardiovascular and strength training[26,27]. The health benefits are vast and the buoyant effect of the water makes this non-weight-bearing sport one of low injury risk for those participating at recreational levels[8,27]. Despite the documented health benefits, swimmers competing at elite levels are predisposed to musculoskeletal injuries[26–28]. This is due to the highly repetitive motion of upper and lower extremities, and competitive swimming being a year round sport[26,28,29]. Therefore, competitive swimmers complete strenuous training regimes without the respite of an off-season. Nonetheless, the epidemiology of swimming injuries in general has been poorly represented in literature[27,29,30].

Adolescent sport participation has increased in recent years[11,12,31,32]. This increased sport involvement from young ages throughout the growth phase has raised concerns about injury severity and risk[12]. Adolescent athletes are in a particularly vulnerable phase of life as physiological factors and rapid biological developments contribute greatly to their increased injury risk[33–36]. Sports injuries in young athletes have been identified as having the potential to significantly reduce adult quality of life[35]. Despite young athletes' increased injury susceptibility, the epidemiology of sports injuries in adolescents has been largely overlooked[12,33,37]. Furthermore, the comparison of injury incidence in youth across different sports is difficult for the following reasons: diversity of cultures, study populations, small sample sizes, short periods of data collection, varying injury definitions, low response rates and issues related to study compliance[12].

There has also been an increase in adolescent participation in competitive swimming. There is a growing body of evidence regarding swimming biomechanics, performance and specific injury locations and types[27,29,38]; however there is limited evidence for the epidemiology of injuries in adolescent competitive swimmers[14,32,38,39]. Only one retrospective study has investigated musculoskeletal injuries in competitive adolescent swimmers, and the findings were limited due to the study design[38]. More research is required to determine training loads of competitive adolescent swimmers. Furthermore, investigations of a prospective nature are needed to describe the nature of injuries in adolescent swimmers, and determine which risk factors might be associated with increased injury susceptibility.

1.2 AIMS AND OBJECTIVES

1.2.2 Aim

The aim of this study was to determine injury incidence and potential risk factors for injury in adolescent swimmers over a 24-week period.

1.2.2 Specific objectives

The specific objectives of this study were:

(a) To describe the demographic and training characteristics of competitive adolescent swimmers;

(b) To establish the incidence and nature of self-reported swimming-related injuries in competitive adolescent swimmers; and

(c) To determine if any specific intrinsic factors and extrinsic factors were associated with increased risk of injury in competitive adolescent swimmers.

(d)

1.2.3 Significance of this study

There is very little literature regarding the incidence of swimming-related injuries in adolescents. Physiological factors, specific to the adolescent age-group, increase injury susceptibility during this phase of life. Information obtained from this study aims to contribute to the limited knowledge on the nature and incidence of injuries in adolescent swimmers by evaluating potential risk factors. The training data reported will also provide some insight regarding the training regimes of competitive young swimmers in Johannesburg, South Africa. Information surrounding the nature of injuries and training volumes could help inform the development of screening and injury prevention programmes for young swimmers.

1.3 PLAN OF DEVELOPMENT

In preparation for the experimental phase of this dissertation, a comprehensive review of the literature on swimming as a sport, adolescent sports participation, adolescent swimming injuries and the specific risk factors increasing adolescent swimming injury susceptibility will be presented (Chapter 2). This will be followed by a descriptive, prospective, longitudinal study that was designed to investigate the injury incidence and training volumes of competitive adolescent swimmers (Chapter 3). A summary and conclusion section, including recommendations for future research, will complete this dissertation (Chapter 4).

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

Swimming is a popular sport performed by people of varying ages and genders worldwide[8,27]. Despite its popularity, limited literature exists with regard to competitive swimming as a sport when compared to popular land-based sports such as soccer or rugby. Notwithstanding the discrepancies between literature available for different sporting types, the consensus is that there has been a recent surge in adolescent participation across a multitude of sports[12,31,32,34,40]. It can be deduced that the adolescent population partaking in competitive swimming has thus also increased. Despite the positive health benefits achieved through swimming, the negative aspect is that an overall growth in swimming popularity and participation has resulted in increased injury incidence over the years. This rise in injury incidence coupled with adolescent athletes' vulnerability to sustaining injuries, place adolescent swimmers in a higher risk category compared to adult counterparts. Previous studies have investigated the swimming injury incidence of purely adult[29,30] or combined adult-adolescent cohorts[41,42]; only one study was found that retrospectively evaluated swimming injury incidence in adolescents once-off[38]. There were no prospective studies found that investigated swimming injury incidence in a purely adolescent swimming population over a period of time.

The purpose of this review is to elaborate on aspects of swimming as a sport, discuss general adolescent sport participation and specific adolescent swimming participation. The nature, incidence and operational definitions of adult and adolescent swimming injuries will be highlighted. The review will also examine potential risk factors for swimming-related injuries, some of which are exclusive to adolescent swimmers.

Online databases searched for articles included PubMed, EbscoHost, Science Direct, Medline and Google scholar. Articles provided by UCT lecturers were also used. The following keywords and varying combinations of these were used: '*swimming', 'competitive swimmers', 'injury', 'sport's injury', 'swimming injury', 'prevalence', 'adolescent', 'adolescent injuries', 'adolescent swimming', 'athletic exposure', 'injury incidence', 'risk factors', 'intrinsic', 'extrinsic', 'modifiable', 'non-modifiable', 'hand held dynamometer', 'Beighton Score', 'injury report questionnaire', 'medical history questionnaire' and 'glenohumeral internal rotation deficit'.*

2.2 OVERVIEW OF SWIMMING AS A SPORT

Swimming is a non-weight-bearing sport involving elements of cardiovascular training in combination with upper and lower limb strengthening[6,26]. Swimming is performed at both recreational and competitive levels[27,29,43,44]; 100-120 million people in the United States of America (USA) enjoy recreational swimming[8]. Over 42 000 swimmers have competed at National Collegiate Athletic Association (NCAA) Division I-A levels in the USA in the last 25 years[29]. In competitive swimming internationally, a total of 40 swimming events are recognised; only 32 events are recognised in the Olympics[45]. These events encompass four strokes specified by the International Swimming Federation (FINA): butterfly, backstroke, breaststroke and freestyle[8,45,46]. Regardless of a swimmer's stroke preference or competitive stroke affinity, the majority of training time is devoted to swimming freestyle[8,26,47].

Competitive swimming training sessions and events are held in both indoor and outdoor pools, facilitating participation all year round. In some countries, two official swimming seasons are recognised throughout the year: short and long course seasons. The difference between short and long course seasons lies in the length of the pool used for training and events (i.e. 25-meter (m) or 50m swimming pools respectively). In other countries, swim seasons correspond with either calendar or academic school years[29]. South Africa has no designated swimming season[6,13,44]. Local competition events are generally held in outdoor pools in the summer months, from late October until early April[13]. Anecdotally, according to swim coaches, South Africa has summer and winter training seasons. Winter is known as the off-season and training is dedicated towards both land-training and water-based strengthening. October generally marks the start of the summer competitive season at school, club and master's levels in South Africa[13]. The junior and senior regional and national championships take place towards the beginning of April annually[13]. These championships usually signal the end of an extensive six-month summer training period[13].

2.3 ADOLESCENT SPORT PARTICIPATION

2.3.1 Overview of the adolescent period

Adolescence is defined as the transient period of human growth, from the onset of puberty to the development of adulthood[48,49]. The World Health Organisation states that the rapid physical growth rate in this phase of life is superseded only by that of the infancy phase[49]. The performance of regular physical activity during this period is imperative and will be elaborated on in Section 2.3.2.

The biological developments and changes occurring during this time are similar for adolescents worldwide[49]. This process of maturation terminates legally when the age of majority is reached[48]. Thus, 18 years marks the end of adolescence[36]. It is understood that this period extends predominantly over the teenage years, but it is disputed where the age range of adolescence starts.

The reason being that the duration and individual characteristics of the adolescent phase vary across cultures, socioeconomic status and time[49]. Some authors are of the opinion that the start of adolescence should be 13 years[35,36,47]. Others maintain that 12 years marks the beginning of this phase[50,51]. The World Health Organisation believes adolescence to begin at the early age of 10 years. It seems the trend is that the beginning of adolescence is becoming earlier each century for some of the following reasons: urbanisation, increased global communication, earlier sexual ripening, earlier economic independence and later age of marriage[49].

Adolescents are generally thought to attend secondary or high-school. However, since the academic school years commence at varying times throughout the year internationally (commonly after the summer holidays), some adolescents may still attend primary-school. It is customary for South African first graders to be seven years old[52], but not uncommon to be sent to school aged five or six. The South African Department of Education stipulates that children may attend grade one, providing they turn six years old no later than the thirtieth of June that year[53,54]. Hence, following primary-school attendance, high-school in South Africa is usually commenced between the ages of 12 to 13 years. For purposes of this study (based in a South African setting) the adolescent age will be accepted as ranging from 12 to 18 years[50].

2.3.2 The importance of sport participation during adolescence

Partaking in regular exercise and sport is vital during the period of adolescent growth[12,34,55,56]. One important benefit of regular weight-bearing exercise during rapid growth periods can be seen in the improvement of bone mineral content and bone density[57]. It is stated that physical activity for this population should be dynamic, variable in speed and direction and performed intermittently with rest periods[58–60]. Moderate to high-impact exercises optimise bone health by loading certain skeletal sites which increases bone formation at both periosteal and endosteal surfaces of long bones[59]. Health benefits further include improved aerobic fitness, muscular strength and body composition with regular physical activity[61]. The psychological benefits of exercise are also widely documented and relate mostly to improved self-confidence and body image[58,61]. Authors believe that children and adolescents who partake in regular sporting activities are more likely to continue this behaviour into adulthood[59,61]. This reduces the risk of chronic diseases later in life because it is known that physical inactivity significantly increases risk of hypertension, cardiovascular disease, hypercholesterolemia, diabetes and obesity to name a few[58,59].

At this point a distinction must be made between adolescents partaking in regular physical activities and those competing at elite levels in sports. The sample population of this study falls into the latter group, meaning they partake in specific training sessions that are more structured and rigorous[60]. While the benefits of exercise and sport participation are bountiful, the danger of overload (i.e. overexposure) with excessive physical loading may have negative biological, psychological and social consequences[60,61]. For example, heavy weight lifting has been said to cause epiphyseal damage which significantly impacts the growing skeletal system[60]. Psychological consequences of overload include the risk of aversion to sport, injured risk of injury, early drop-out and apathy resulting from burn-out[58,60,61]. It was found that approximately 8% of adolescents drop out of future sporting activities as a result of injury[34,50]. This precipitates the cycle of lacking physical activity in adult years, which again has the potential to offset a multitude of chronic diseases.

To reduce the risk of over-load and injuries the International Federation of Sports Medicine (FIMS)[60] compiled a position statement to guide parents, teachers and coaches with regard to exercise prescription of competitive young athletes. Since there is no consensus as to what the ideal dose of exercise prescription for adolescent athletes is, tailor-made programmes (incorporating exercise frequency, intensity, level of difficulty and duration) are essential after completing thorough medical examinations[58,60].

2.3.3 Epidemiology of adolescent sport participation

Adolescent sport participation has gained popularity internationally in the last 20 to 30 years[12,31,32,34,40,61]; most organised sport is now performed by children and adolescents[33]. Half of all individuals aged five to 18 years in the United States are said to participate in organised sports programmes, corresponding to a figure in excess of 30 million individuals[7,36,62]. A survey conducted in the USA in 2013 found that 47% of all high-school individuals performed a minimum of 60 minutes of exercise at least five days a week[63]. It was also found that 48% attended school-organised physical education classes at least once a week and 54% of adolescents were members of at least one sports team in the last 12 months[63]. Similarly, in Canada, 70% of adolescents partake in organised sport outside of school of which 64% complete at least one hour per week for an entire year.

Internationally, other studies report similar findings for adolescent sport participation[11,37]. From these data, it seems that the adolescent age group in the USA has recently become one of the most studied cohorts due to easy accesibility[7,12]. Internationally, however, organised youth sports have not yet demanded the same amount of attention and injury surveillance studies of this age-group are scarce[7,37,64]. Injuries in adolescent sports are very common due to increased exposure and overload. These injuries will be looked at in more detail in the sections that follow.

2.4 OVERVIEW OF ADOLESCENT SPORTS INJURIES

2.4.1 Adolescent sports injuries as a public health concern

Increased global sports participation from relatively young ages, coupled with limited injury data and statistics for this age-group has fuelled concerns about the risk and severity of youth sports injuries[12,34,35]. Sport's injuries are related to or sustained during participation in sport[7] and interfere with further participation in physical activity[65–67]. A comprehensive definition is provided in Section 2.7.1 (page 35). Sport's injuries are the leading cause of injuries in the adolescent population[32–34,37,50], and have even been described as a "*public health concern*[35(p2)]". This description infers that sports injuries significantly impact physical, social, economic, psychological and financial factors. Prevention of injuries in the adolescent age group should thus be aimed at improving well-being in later stages of life[34]. In the paragraphs that follow these factors will be elaborated on to demonstrate the far-reaching effects these injuries could have.

Physical well-being after injury is affected in many ways. Severe injuries to an immature skeletal system impair growth; this has the potential to reduce adult quality of life because future normal physical development is affected[33–37,40,56]. Some injuries may hamper participation to such an extent that an athlete is forced to drop out of sports events. This drop-out results in a reduction and in some cases cessation of physical activity. The importance of physical activity during the adolescent phase in preventing chronic diseases in adults was discussed in Section 2.3.2 (page 5). Physiologically, sports injuries have also been found to accelerate early onset of osteoarthritis in later stages of life[34,35,50]. This degenerative joint disease may negatively impact the quality of life resulting in disability and reduced ability to perform activities of daily living[35]. Activities of daily living include social activities like attending church, community functions and projects. Reduced physical ability and attendance further impact social and psychological well-being.

Anecdotally, it is thought that withdrawal from society may lead to depression. Sport drop-out in itself may also have psychological consequences[61,67]. Negative feelings of poor self-esteem, body image and self-worth may arise from reduced participation in sporting activities[67]. This could negatively impact inter-personal relationships and productivity. It could be inferred that economic well-being is then affected if an employee in no longer as productive at work. Economic well-being decreases further if employees are forced to take numerous sick days on account of physical or psychological ill-health. Injured individuals additionally face financial burdens due to the cost of medical bills (i.e. general practitioner or specialist consults, medication, surgery and rehabilitation). Not only injured individuals themselves are privy to financial burdens: the state and medical aids are often required to absorb high costs of surgery or lengthy rehabilitation processes. In the USA, child and adolescent sports related injuries cost the state more than 1.8 billion dollars per year[31,34,36,40].

In Canada an estimated one in four adolescents seeks medical attention for a sports injury[34]. Despite these costs to individuals and the state, the epidemiology of sports injuries in adolescents has been largely overlooked[12,33,36,37].

2.4.2 Adolescent's increased risk for sports injuries

Adolescents are at high risk of sustaining sport-related injuries because the biological development occurring during this phase of life is incredibly fast[33,51,68]. One of the main reasons for adolescents' increased vulnerability lies in the structure of the growing musculoskeletal system. Growing bone differs from mature, adult bone in the following ways: thicker articular cartilage; easily disrupted junctions between metaphyses and epiphyseal plates; apophyses providing weak sites for tendon attachments; rapid bone growth relative to tendons and muscles. These factors are explained in greater detail in Section 2.6.2.1 (page 28). As a result of these physiological differences, younger athletes are more likely than adults to present with injuries to cartilage, bone and apophyses[58]. The growth plates, specific to non-mature skeletal systems, also provide sites for common injuries and result in a group of conditions known as osteochondroses[58].

Compared to adults, younger athletes also have a large surface area to mass ratio. This means they also have larger heads, resulting in a greater number of head injuries[36]. Compared to children, athletic adolescents have more circulating androgens therefore greater masses, speed and subsequent power[36]. This, coupled with impulsive, sometimes reckless, behaviour and infinite energy seen in pubescent adolescents, further increases this population's risk of injury[36]. Therefore, adolescents physiological vulnerability combined with high levels of athletic exposure[50] has placed adolescents in a greater risk category compared to younger children and adults[11,37]. This is supported by literature that demonstrates visits to the emergency department are higher in children (five to twelve years old), adolescents (12 – 18 years) and young adults (18 – 24 years) compared to any other age-group[36,69].

2.4.3 Epidemiology of adolescent general sports injury incidence

After establishing that adolescent sports injuries are an increasing global concern, it is necessary to quantify actual injury incidence of this population. An overview of studies evaluating the epidemiology of adolescent sport injury incidence is depicted in Table 2.1[*]. The purpose of this table is to compare injury incidence of young athletes between different sporting types. It is evident from the table that land-based sports have higher injury incidence compared to swimming.

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[*] Level of evidence (LoE) rating scale (adapted from material published by Centre for Evidence-based Medicine, Oxford, UK) was the used in the Journal and Joint Surgery (Appendix 1)

Table 2.1: Summary of some studies evaluating epidemiology of injury incidence in adolescents.

Article	Study design	Participants	Participant age (y)	Type of sport	Duration of injury surveillance	Method of injury surveillance	Injury incidence	Injury rate
Baxter-Jones et al.[70]	LoE: IV	453 elite athletes 231 male 222 female	8 - 16	Soccer Gymnastics Tennis Swimming	3 y	Medical interview Exposure data sheet	40 injuries per 100 athletes > 1 injury per 1 000 AE's: Soccer 67% Gymnastics 65% Tennis 52% Swimming 37%	Not reported
Brooks et al.[32]	LoE: IV	451 competitive high-school athletes 342 male soccer players 127 track athletes (68 % male)		Soccer Track	1 y	Self-administered questionnaire	241 (53%) athletes ≥ 1 injury during 1 y	Not reported
Goldberg et al.[7]	LoE: III	High-school athletes	No age restriction (mostly adolescents)	Basketball Soccer Football	N/A	Searches of Ovid Medline and PubMed	Not reported	Not reported

Key: LoE- Level of Evidence; y - year; wk - week; PPE- preventative pre-participation evaluation; N/A- not applicable; AE's - athletic exposures; CHRIPP - Canadian Hospitals Injury Reporting and Prevention Program; BCCH- British Columbia Children's Hospital.

Table 2.1: Summary of some studies evaluating epidemiology of injury incidence in adolescents continued.

Article	Study design	Participants	Participant age (y)	Type of sport	Duration of injury surveillance	Method of injury surveillance	Injury incidence	Injury rate
Habelt[33]	LoE: IV	17 397 total patients 67% male 33% female		Soccer Handball Skiing Biking Swimming	10 y	Computer data program	4 468 injuries in patients aged 10 – 19 y Proportions of injuries: soccer 31% handball 9% skiing 6% biking 6% swimming 1%	Not reported
Emery et al.[51]	LoE:III	334 competitive players of 21 soccer teams	12 - 18	Soccer	13 wk	Weekly exposure sheet	Not reported	5.6 injuries / 1 000 player hours
Emery et al.[34]	LoE: III	1 466 Students from 35 junior high schools	12 - 15	Basketball Soccer Hockey Skiing	1 y	Retrospective questionnaire	892 students ≥ 1 injury during 1 y Proportions of injuries: Basketball 14% Soccer 12% Hockey 9% Skiing 7%	Injury rates presented as injury / 100 students / y: Overall injuries: 60.9 Injuries requiring medical attention: 29.4 Injuries presenting to ER: 12.3 Time loss injuries: 36.3

Key: LoE- Level of Evidence; y - year; wk - week; PPE- preventative pre-participation evaluation; N/A- not applicable; AE's - athletic exposures; CHRIPP - Canadian Hospitals Injury Reporting and Prevention Program; BCCH- British Columbia Children's Hospital.

Table 2.1: Summary of some studies evaluating epidemiology of injury incidence in adolescents continued.

Article	Study design	Participants	Participant age (y)	Type of sport	Duration of injury surveillance	Method of injury surveillance	Injury incidence	Injury rate
Caine et al.[12]	LoE: IV	N/A - Review	N/A	Ice hockey Rugby Soccer Football Basketball Gymnastics	N/A	Database search	Highest overall injury incidence in football for boys and soccer for girls	Injury rates presented as injury / 1 000 AE's: Males: Ice hockey 5.0 – 34.4 Rugby 3.4 – 13.3 Soccer 2.3 – 7.9 Females: Soccer 2.5 – 10.6 Basketball 3.6 – 4.1 Gymnastics 0.5 – 4.1
Fuller et al.[3]	Consensus statement	≥ 1 football team.	N/A	Soccer	Minimum of 1 season / 12 months / tournament duration	Standardised data collection forms	Not reported	Not reported

Key: LoE- Level of Evidence; y - year; wk - week; PPE- preventative pre-participation evaluation; N/A- not applicable; AE's - athletic exposures; CHRIPP - Canadian Hospitals Injury Reporting and Prevention Program; BCCH- British Columbia Children's Hospital

Table 2.1: Summary of some studies evaluating epidemiology of injury incidence in adolescents continued.

Article	Study design	Participants	Participant age (y)	Type of sport	Duration of injury surveillance	Method of injury surveillance	Injury incidence	Injury rate
Pakzad-Vaezi & Singhal[40]	LoE: III	Competitive young athletes	5 -9 10 – 14 15 - 19	All sport	14 y	CHIRPP	27 460 sports injuries 28% increase in injuries during study period Proportions of injuries: Cycling 14% Basketball 12% Soccer 11% Ice hockey 5%	Not reported
Schneider et al.[37]	LoE: III	7 451 adolescents 3 800 male 3 651 female	11 - 17		3 y (1 y was retrospective reporting)	German health interview Examination survey for children and adolescents	577 injuries during study period	Not reported

Key: LoE- Level of Evidence; y - year; wk - week; PPE- preventative pre-participation evaluation; N/A- not applicable; AE's - athletic exposures; CHRIPP - Canadian Hospitals Injury Reporting and Prevention Program; BCCH- British Columbia Children's Hospital

"It is difficult to obtain data on the relative risks (based on injury rates) of various types of sports for youth because exposure data across sports are limited[36(p76)]*"*. Despite deficient data on overall adolescent injury incidence, two studies investigated incidence rates relative to exposure levels of 1 000 participation hours. These studies found injury rates to range from 2.38 to 142.86[11,34]. Other literature documented injury incidence per 100 adolescent participants, with a range of 2.60 to > 100.00[11,12,68,70]. The literature reporting injury rates in adult competitive athletes is far more extensive. For example, Yang et al.[1] performed a study on 16 collegiate sports teams over three years and determined injury rates of 63.10 per 10 000 athletic exposures (AE's). Similarly the National Collegiate Athletic Association (NCAA) reported injury rates for over 15 different types of sport in adult college athletes[19]. Overall, competition injury rates of 13.80 per 1 000 AE's were greater than those incurred during training sessions (4.00 injuries per 1 000 AE's)[19].

Injury rates for adolescent girls are higher in sports like gymnastics, basketball and soccer; for boys hockey, basketball and football have highest injury rates[11,12]. Comparatively, low injury rates are found in swimming, tennis and badminton participation[11,68,70]. An injury incidence study with a large adult cohort found football to have much higher injury risk than either baseball or softball[19]. In adolescents, football also appears to have high risk of injury relative to swimming[68,70] with rates of 41 – 61% athletes injured annually[36]. In adult football players, injury rates determined by the NCAA were 9.60 and 35.90 per 1 000 AE's for practices and competitions respectively.

In European professional men's soccer, injury rate was 8.00 per 1 000 player hours over seven years[24]; an average of two injuries per player were sustained each season. Overall injury rates in adult male professional soccer players in South Africa were reported as 13.40 per 1 000 player hours over one season[71]. Research surrounding injury incidence in soccer is extensive[3], while swimming injury incidence data is scarce[12]. No study to date has prospectively investigated swimming injury incidence over one season in a purely competitive adolescent swimming population. For this reason it is necessary for literature to focus on expanding knowledge with regards to both general adolescent injury incidence and youth swimming injury incidence.

2.4.3.1 Epidemiology of adolescent swimming injury incidence

A summary of studies investigating swimming injury incidence is depicted in Table 2.2 which highlights how few studies investigate overall injury incidence in swimmers. Many of the studies include mixed adult-adolescent cohorts showing that there are fewer swimming related studies that have a purely adolescent focus. The definition of the term 'swimming injury' is provided in Section 2.5 (page 24).

Rigorous training regimes have raised concerns regarding the severity and incidence of injuries affecting swimmers[30]. The sequential and repetitive limb action in swimmers is believed to increase the likelihood of sustaining injuries over time, which impact physical, emotional and mental well-being and significantly contribute to reduced performance time[8,26,41,72]. Current swimming literature focusses predominantly on adult swimmers in the USA, Europe and Australia[8,12,19,20,26,29,30,41,73], competing at international, collegiate or professional levels. Numerous epidemiological studies of adult swimmers have examined specific swimming injury locations and types[8,26,29,30,41], yet limited published information exists regarding the overall incidence and distribution of swimming injuries in adults[29,30,38]. Research involving young swimmers is more uncommon than adult / elite counterparts[74]. Overall swimming injury incidence for South African swimmers is unknown; to date only studies investigating 'swimmer's shoulder' have been conducted in a South African setting[6,44].

Wolf et al.[29] investigated injury incidence of elite, collegiate swimmers in the USA[29]. Injury rates demonstrated 4.00 injuries per 1 000 training hours in men and 3.78 for women over a five year period[26,29]. Another study by Chase et al.[30] revealed 5.33 and 6.50 injuries per 1 000 athletic exposures for male and female swimmers respectively[30]. Although both these studies assessed adult populations, some swimming injury incidence studies have combined both adolescent and adult cohorts across a wide range of ages[8,14,20,32,38,39,41,42]. Previous studies of adolescent swimmers have evaluated specific aspects of injury location / type, performance, risk factors, anthropometrics, and prevention and training programmes[8,14,38,41,75,76]. Only one study, which retrospectively investigated musculoskeletal swimming injuries in an adolescent Greek population once-off, was found[38]. The incidence rate was not reported because the aim of the study was only to describe the pattern of injuries in adolescent swimmers.

Table 2.2: Summary of studies evaluating injuries in adult- adolescent cohorts of competitive swimmers.

Article	Study design	Participants	Participant age (y)	Objective	Study period	Results
Walker et al.[41]	LoE: III	74 competitive swimmers performing minimum of 5 swim sessions per wk 37 male 37 female	11 - 27	To determine shoulder pain incidence rates and selected risk factors	12 months	Exposure incidence rates: Significant interfering shoulder pain: 0.3 / 1 000 km Significant shoulder injury: 0.4 / 1 000 km Swimming exposure (km): 6 ± 1 / session 44 ± 15 / wk
Tate et al.[42]	LoE: III	234 competitive female swimmers	8 - 77	To determine whether physical characteristics, training variables or exposure differs between swimmers with and without shoulder pain	Once-off	Shoulder pain and disability in: 21.4% 8 - 11 y; 18.6% 12 - 14 y; 22.6% 15 - 19 y; 19.4% 23 - 77 y. High-school swimmers most symptomatic Swimming exposure with shoulder pain (h) / wk: 8 - 11 y: 7.8 ± 2.9 12 - 14 y: 10.9 ± 4.3 15 - 19 y: 16.5 ± 5.5 23 -77 y: 4.8 ± 1.5 ↑ exposure in adolescents accounts for more injuries

Key: wk- week; y- year; km- kilometer; ER- external rotation; IR- internal rotation; h- hour; PROM- passive range of motion; AE- athletic exposure; N/A- not applicable; C_S- metabolic energy ; VO_{2peak}- peak oxygen uptake; TT- time trial; m- meter; SI- stroke index; SR- stroke rate; SL- stroke length; D_a- Active drag force.

Table 2.2: Summary of studies evaluating injuries in adult- adolescent cohorts of competitive swimmers continued.

Article	Study design	Participants	Participant age (y)	Objective	Study period	Results
Kruger et al.[6]	LoE: III	282 masters swimmers 136 male 144 female	25 - 75	To determine the incidence of shoulder pain in master swimmers in South Africa To determine if a relationship exists between selected risk factors and occurrence of shoulder pain among the master swimmers	Once-off (retrospective over 3 y)	62.4% incidence of shoulder pain in a 3 y period Training exposure(volume): Low: 0 – 4 999 m / wk Medium: 5 000 – 11 999 m / wk High: ≥ 12 000 m / wk
Chase et al.[30]	LoE: III	34 swimmers of NCAA division 1 Midwest University 16 male 18 female	18 - 23	To determine incidence and distribution of injuries To determine potential risk factors	8 months	Injury rates per 1 000 AE's: Females: 6.1 Males: 5.0 Injury rates per 1 000 h of practice: Females: 3.3 Males: 2.8 Shoulder 38.7% Back 16.1% Knee 12.9% No significant difference between genders

Key: wk- week; y- year; km- kilometer; ER- external rotation; IR- internal rotation; h- hour; PROM- passive range of motion; AE- athletic exposure; N/A- not applicable; C_S- metabolic energy ; VO_{2peak}- peak oxygen uptake; TT- time trial; m- meter; SI- stroke index; SR- stroke rate; SL- stroke length; D_a- Active drag force.

Table 2.2: Summary of studies evaluating injuries in adult- adolescent cohorts of competitive swimmers continued.

Article	Study design	Participants	Participant age (y)	Objective	Study period	Results
Wolf et al.[29]	LoE: III	94 swimmers of NCAA division 1 University of Iowa 44 male 50 female	≥ 17	To describe the pattern of injuries incurred for one NCAA Division I collegiate men's and women's swimming team over 5 seasons	12 months for 5 y (2002 - 2007)	Injury rates per 1 000 AE's: Females: 3.8 Males: 4.0 Shoulder / upper arm 58.5%; Back / neck 40.4%; Forearm 25.5%. No significant differences between genders
Bak and Fauno.[20]	LoE: IV	36 competitive swimmers with history of interfering shoulder pain 14 male 22 female	12 - 23	To determine the clinical findings in competitive swimmers with shoulder pain	1 season of 1 y (1994 - 1995)	Shoulder pain (n): Unilateral 23 Bilateral 13 (half National Team swimmers and correlated with longer history of swimming) High level coracoacromial impingement associated with glenohumeral translation and positive apprehension; shoulder laxity antero-inferior Swimming exposure (km): 33.1 / wk 1581 / y
Gaunt and Maffulli[27]	LoE: II	Competitive swimmers	No age limit was set	A systematic review of the epidemiology, diagnoses, treatment and rehabilitation of musculoskeletal injuries in competitive swimmers	25 y (1985 – 2010)	First systematic review on swimming injuries Apprehension test common in all studies evaluating shoulder clinical features Recommend Beighton grading be used for assessment of swimmers

Key: wk- week; y- year; km- kilometer; ER- external rotation; IR- internal rotation; h- hour; PROM- passive range of motion; AE- athletic exposure; N/A- not applicable; C_S- metabolic energy ; VO_{2peak}- peak oxygen uptake; TT- time trial; m- meter; SI- stroke index; SR- stroke rate; SL- stroke length; D_a- Active drag force.

Table 2.2: Summary of studies evaluating injuries in adult- adolescent cohorts of competitive swimmers continued.

Article	Study design	Participants	Participant age (y)	Objective	Study period	Results
Sein et al.[8]	LoE: III	80 elite swimmers (minimum 2.5 y of formal coaching)	13 - 25	To test Jobe's hypothesis that repetitive forceful swimming leads to shoulder laxity and in turn impingement syndrome	Once-off	Weak correlation of laxity with impingement and no correlation with supraspinatus tendinopathy Swimming exposure (mostly freestyle): 90 - 110 km /wk 8 - 29 h / wk
Wanivenhaus et al.[26]	LoE: IV	N/A	N/A	To discuss epidemiology of upper limb, knee and spine injuries To determine prevention strategies and rehabilitation programmes for swimmers after injury	39 y (1972 – 2011)	Shoulder injury most common (prevalence 40 - 91%) Knee injuries second most common usually due to breaststroke; usually medial or anterior compartment Spine intervertebral disc degeneration (68% prevalence)
Grote et al.[28]	LoE: III	296 competitive swimmers	16 - 22	To assess the incidence and importance of interfering groin pain in breaststroke swimmers	Once-off	Groin injury positively correlated with ↑ magnitude of breaststroke training 42.7% breaststroke swimmers more likely than IM ($p = 0.0006$) or non-breaststroke ($p = 0.000003$) swimmers unable to train breaststroke the past year due to groin injury

Key: wk- week; y- year; km- kilometer; ER- external rotation; IR- internal rotation; h- hour; PROM- passive range of motion; AE- athletic exposure; N/A- not applicable; C_S- metabolic energy ; VO_{2peak}- peak oxygen uptake; TT- time trial; m- meter; SI- stroke index; SR- stroke rate; SL- stroke length; D_a- Active drag force.

Table 2.2: Summary of studies evaluating injuries in adult- adolescent cohorts of competitive swimmers continued.

Article	Study design	Participants	Participant age (y)	Objective	Study period	Results
Rodeo[77]	LoE: V	N/A	N/A	To review the incidence, biomechanical and anatomic factors predisposing to injury, specific injury patterns, injury diagnosis, treatment and prevention of injury to the knee in swimmers	Review	Knee injury prevalence in 10 - 75% of swimmers Mostly occurs in medial compartment and usually in breaststroke swimmers
Harrington et al.[78]	LoE: III	37 competitive female swimmers from NCAA division 1	18 -20	To determine if differences exist in shoulder ROM, upper-extremity strength, core endurance and pectoralis minor length in swimmers with and without shoulder pain and disability	Once-off	Significantly ↓muscle length at both rest and stretch for the positive shoulder pain participants No other statistically significant measures were found for the other dependent variables on either the dominant or non-dominant arm
Brushøj et al.[79]	LoE: III	18 competitive swimmers (all had shoulder arthroscopy)	16 aged: 16 - 22 Surgery age: 15 - 34	To describe operative findings after arthroscopy of swimmers' painful shoulder To evaluate the outcome of arthroscopic treatment with regard to the rate of return to sport	8 y (1992 - 2000)	Arthroscopy findings: labral pathology: 61% subacromial impingement: 28% Time to return to swimming at the pre--injury level was 2 – 9 months and 56% participants returned

Key: wk- week; y- year; km- kilometer; ER- external rotation; IR- internal rotation; h- hour; PROM- passive range of motion; AE- athletic exposure; N/A- not applicable; C_S- metabolic energy ; VO_{2peak}- peak oxygen uptake; TT- time trial; m- meter; SI- stroke index; SR- stroke rate; SL- stroke length; D_a- Active drag force.

Table 2.2: Summary of studies evaluating injuries in adult- adolescent cohorts of competitive swimmers continued.

Article	**Study design**	**Participants**	**Participant age (y)**	**Objective**	**Study period**	**Results**
Batalha et al.[80]	LoE:III	20 national-level male swimmers	13 - 15	To analyse the effects of a competitive swim season on the strength, balance and endurance of shoulder rotator cuff muscles in young swimmers	1 swim season of 31 wk	Huge differences in IR / ER from start to end of season A competitive swim season favours increase in IR strength compared to ER Strength imbalance between rotators may lead to chronic upper-extremity overuse injury
Sambanis et al.[38]	LoE: III	149 competitive swimmers 76 male 73 female	11 - 16	To determine the pattern of musculoskeletal injuries in teenage Greek swimmers	Once-off assessment (follow-up over 2 y)	48 swimmers reported MSK pain; 26 male, 22 female Shoulder pain: 62.5% Knee pain: 22.9% Low back pain: 14.6% Training exposure (h): Females: 12.6 ± 1.7 Males: 12.5 ± 1.6

Key: wk- week; y- year; km- kilometer; ER- external rotation; IR- internal rotation; h- hour; PROM- passive range of motion; AE- athletic exposure; N/A- not applicable; C_S- metabolic energy ; VO_{2peak}- peak oxygen uptake; TT- time trial; m- meter; SI- stroke index; SR- stroke rate; SL- stroke length; D_a- Active drag force.

Table 2.2: Summary of studies evaluating injuries in adult- adolescent cohorts of competitive swimmers continued.

Article	Study design	Participants	Participant age (y)	Objective	Study period	Results
Jürimäe et al.[81]	LoE:III	2 groups of competitive swimmers	11 - 15	Assess C_s in pre-pubertal and pubertal boys Compare indirect in-water measurement of VO_{2peak} with laboratory-based measurement of VO_{2peak} Examine the influence of C_s, anthropometrical, body composition and technical parameters on swimming performance in pre-pubertal and pubertal boys	Once-off	Mean exposure: 19.4 ± 5.5 km / wk The backward-extrapolation method of assessing VO_{2peak} after 400-m TT can be used in training/ testing programmes for competitive young swimmers C_S evaluation allows estimation of energy expenditure during swimming training and can be used to assess the training load SI, arm span and VO_{2peak} appear to be the major determinants of freestyle swimming performance in young swimmers
Mezzaroba et al.[82]	LoE:III	Young competitive swimmers	10 - 16	To determine the group of parameters that best predict short and middle swimming distance performances of young swimmers of both genders.	2 wk	Considerable differences between genders in short- and middle distance swimming Males had more variables included than females when considering predictors Biomechanical variables best predicted 100-m TT for both genders and 200-m TT for females Physiological variables best predicted 400-m TT for both genders and 200-m TT for males

Key: wk- week; y- year; km- kilometer; ER- external rotation; IR- internal rotation; h- hour; PROM- passive range of motion; AE- athletic exposure; N/A- not applicable; C_S- metabolic energy ; VO_{2peak}- peak oxygen uptake; TT- time trial; m- meter; SI- stroke index; SR- stroke rate; SL- stroke length; D_a- Active drag force.

Table 2.2: Summary of studies evaluating injuries in adult- adolescent cohorts of competitive swimmers continued.

Article	Study design	Participants	Participant age (y)	Objective	Study period	Results
van der Velde et al.[83]	LoE:II	Competitive swimmers Control group: 16 sedentary male students	13 - 16	To evaluate isokinetic scapular-muscle performance and to compare the results of training programs designed for strength or muscle endurance	12 wk	Both muscle-strength and muscle-endurance programmes improved absolute muscle strength Neither programme had a positive effect on scapula muscle endurance
Krabak et al.[84]	LoE:II	97 coaches of young swimmers from different clubs	≤10 - ≥18	To describe the current use of dry-land training in swimmers by age category	Once-off	50 - 93% of coaches incorporated dry-land training Swimmers < 18 y do core strength 15 - 18 y-old swimmers do the most dry-land training Body weight exercises are used in younger swimmers
Lätt et al.[39]	LoE:III	Male swimmers	13 - 17	To analyse the relationships between 100- m freestyle swimming performance and relevant biomechanical, anthropometrical and physiological parameters in swimmers	2 d	Biomechanical factors (93%) explained 100-m performance variability in study population, followed by anthropometrical (45.8%) and physiological (45.2%) parameters SI was the best single predictor of performance

Key: wk- week; y- year; km- kilometer; ER- external rotation; IR- internal rotation; h- hour; PROM- passive range of motion; AE- athletic exposure; N/A- not applicable; C_S- metabolic energy ; VO_{2peak}- peak oxygen uptake; TT- time trial; m- meter; SI- stroke index; SR- stroke rate; SL- stroke length; D_a- Active drag force.

Table 2.2: Summary of studies evaluating injuries in adult- adolescent cohorts of competitive swimmers continued.

Article	**Study design**	**Participants**	**Participant age (y)**	**Objective**	**Study period**	**Results**
Barbosa et al.[85]	LoE:IV	29 male swimmers	12 -13	To develop a structural equation modelling (path-flow analysis model) for active drag force based on anthropometric, hydrodynamic and biomechanical variables in young swimmers	Once-off	D_a was highly predictable based on selected anthropometrical, biomechanical and hydrodynamic variables Advised to develop new (frontal surface area) FSA estimation equations specific for young swimmers rather than using the ones developed with adult/elite swimmers
McKenna et al.[22]	LoE:III	66 adolescents 43 swimmers 43 non-swimmers	14 -15	To determine: 1) if scapular and humeral head position can predict the development of shoulder pain in swimmers 2) if predictors were applicable to non-swimmers 3) annual rate of shoulder pain adolescent swimmers and non-swimmers.	12 months	Shoulder pain is common in all adolescents No significant difference in annual prevalence and incidence rates of shoulder pain between groups Predictors of shoulder pain include: shorter distance between scapula and spine, and humeral head and acromion and larger BMI

Key: wk- week; y- year; km- kilometer; ER- external rotation; IR- internal rotation; h- hour; PROM- passive range of motion; AE- athletic exposure; N/A- not applicable; C_S- metabolic energy ; VO_{2peak}- peak oxygen uptake; TT- time trial; m- meter; SI- stroke index; SR- stroke rate; SL- stroke length; D_a- Active drag force.

2.5 SWIMMING INJURIES

The broad definition of a 'sports injury' was provided in Section 2.4.1 (page 7). A more detailed description of operational definitions used to classify swimming injuries in this dissertation are described in Section 2.7.1 (page 35). It was necessary to adapt traditional sports injury definitions because many studies providing those definitions investigated adult athletic populations. The definition for 'swimming injury' used in this study needed to be swimming-and adolescent-specific. Hence, only injuries of a musculoskeletal nature occurring in one of the following situations were reported: injury sustained during swimming training or competition, injury sustained during dry-land training, injury sustained during school or extracurricular sports. Young athletes are encouraged to partake in a variety of activities[21,58], thus it was essential to include 'other sport participation' as a potential source for injury in the definition. Additionally, swim coaches often supplement in-pool training with dry-land training[84]. Including these various mechanisms of injury in the 'swimming injury' definition could provide important information on risk factors specific to adolescent swimmers.

2.5.1 Locations of swimming injuries in adults and adolescents

It is necessary to incorporate literature on types of swimming injuries in adults into this section because individual swimming injuries in adolescents have been poorly investigated. Swimming injuries are usually diagnosed clinically; imaging techniques and occasionally invasive procedures are used to confirm diagnostic accuracy[20,27]. Commonly identified swimming injury distributions include the shoulder (prevalence rates 40% to 91%)[8,14,20,22,26,30,41,47,66,72,79,86], the spine (prevalence rates 20% to 50%)[27,29,30,43] and the knee (prevalence rates 10% to 30%)[27,29,75,77]. This data is largely representative of adult swimming populations.

Prevalence rates continue to rise annually due to higher levels of performance and competition together with increased amounts of training[20]. Despite this, knowledge on the epidemiology of general sports injuries and swimming in adolescents is lacking because studies "*only examine adults, specific types of sport or selected time frames (competition periods or seasons)*"[37(p184)]. For this reason, prevalence rates of injuries in purely adolescent swimming populations are unavailable.

The high prevalence rates of shoulder injuries in mixed adult-adolescent swimming cohorts have ensured that this region attracts the most attention in swimming literature[20,22,26,65,66,72,79,87]. 'Swimmer's shoulder' is the term most commonly used to describe any musculoskeletal complaint or pathology in the shoulder region.

Anterior shoulder pain is most common and results from supraspinatus or biceps tendinopathy[47]. Historically, most shoulder complaints were attributed to coraco-acromial impingement from outlet stenosis[79]. Later, authors found instability resulting from ligamentous and muscular dysfunction to be increasingly significant. The understanding of shoulder joint pathology has increased since the use of arthroscopy[79]. Brushøj et al.[79] found labral pathology (61%) to be the leading cause of discomfort, followed by subacromial impingement (28%)[79]. Although consensus is lacking as to what causes shoulder injuries[8], literature consistently denotes two main risk factors: overuse (repetitive microtrauma) and overload (increased training load). Swimmers more prone to shoulder injuries, consistently exhibit intrinsic qualities like increased glenohumeral range of motion, laxity, scapular dyskinesis and rotator cuff imbalances[8,20,27,41,42].

Knee injuries in swimmers are the second most common injury location[26,75,77], however literature investigating these is scarce[27]. It is known that knee pain in swimmers is most often found on the medial aspect of the knee[26]. It usually results from breaststroke swimming, but may occasionally occur from other strokes[26,75]. The breaststroke kick introduces immense valgus loads to the knee as a rapid combination of extension and tibial external rotation is executed. Consequently, the medial compartment undergoes tension stress causing inflammation and sometimes damage to the medial collateral ligament[77]. The lateral compartment of the knee joint simultaneously experiences compression stress potentially causing lateral compartment lesions (i.e. chondral injuries)[27]. Butterfly stroke and drill sets utilising the 'flutter kick' guarantee repetitive quadriceps contraction. This increases patello-femoral load leading to anterior knee pain. Patello-femoral load and contact stresses are further increased by forceful push-off from the wall with the knee in a position of increased flexion[77].

Less common causes of knee pain that must be considered in all adolescent swimmers include: patellar instability and maltracking; increased tibial external rotation; increased femoral anteversion; decreased hip joint internal rotation[77]. Additionally, apohyseal injuries like Osgood-Schlatter and Sinding-Larsen-Johansson disease, osteochondritis dissecans and juvenile rheumatoid arthritis should be considered in adolescent swimmers[12,36]. Meniscus pathology, discoid lateral meniscus, iliotibial band tendinitis and lateral patellar subluxation should not be forgotten in swimmers with unresolving or mechanical type knee pain[77].

In the spine the most common cause of injury are the lumbar discs, frequently associated with degenerative disc disease[88]. In a study of swimmers, those with increased mechanical loading of the vertebral column were found to have significantly increased levels of disc disease particularly at spine levels of L5/S1 vertebrae[26,88]. Most swimmers aim to achieve hyperextension of the lumbar spine as this better enables streamlining[26,89]. Consequentially, the posterior structures of the spine are placed under immense stress, sometimes resulting in spondylolysis and possible spondylolisthesis[26]. Breaststroke and butterfly kick in particular advocate the hyperextended position and when paired with training equipment like pull buoys, kick boards and fins increase the risk for injury[26,88]. Programmes incorporating general strengthening and endurance training are beneficial in preventing shoulder, knee and spine injuries in swimmers[26].

2.6 RISK FACTORS FOR ADOLESCENT SWIMMERS

2.6.1 Overview of risk factors for general sports injuries

A risk factor increases an individual's potential for injury[11,12,58]. Risk factors are classified as extrinsic or intrinsic[58]. Extrinsic factors relate to individuals' environment, for example the weather, equipment used or level of competition. These factors are similar amongst swimmers of the same club or those attending the same practice session / competition. Intrinsic factors refer to individuals' physiological characteristics. These are unique to each swimmer and include parameters like age, level of fitness or biomechanical abnormalities. Extrinsic and intrinsic factors are further subdivided into categories of modifiable versus non-modifiable risk factors. If implementation of a prevention program has the ability to change and reduce the potential risk, it is referred to as a modifiable risk factor. Strength, flexibility and balance fall into this spectrum. Conversely, non-modifiable factors cannot be altered or manipulated. These are elements such as age, gender and weather.

Table 2.3: Potential Risk Factors for Injury in Child and Adolescent Sport[11]

Extrinsic risk factors		**Intrinsic risk factors**	
Non-modifiable	**Potentially modifiable**	**Non-modifiable**	**Potentially modifiable**
Sport played (contact / no contact)	Rules	Previous injury	Fitness level
Level of play (recreational / competitive)	Playing time	Age	Pre-participation sport-specific training
Position played	Playing surface (type / condition)	Sex	Flexibility
Weather	Equipment (protective / footwear)		Strength
Time of season / time of day			Joint stability
			Biomechanics
			Balance / proprioception
			Psychological / social factors

Previous studies have found numerous risk factors which play important roles in swimmers' injury profiles. These will be elaborated on with regards to both adolescent sport participation generally and swimming specifically where possible.

2.6.2 Risk factors for injuries in adolescent swimmers

Table 2.4: Potential risk factors specific to adolescent swimmers

Extrinsic	Intrinsic
Coaches[90,91] (poor health literacy, poor knowledge of age-appropriate training loads, too pushy)	Previous injury history[30]
Parents[56,90,91] (poor health literacy, too pushy)	Larger body mass index[22]
Elite level of competition (increased physical and psychological strain)	Age[11]
Training and competition loads[6,26,27] (overload and not age-appropriate)	Gender[29]
Time of season (mid-season often association with higher training / competition loads)	Strength and flexibility[26,41]
Early specialisation[21]	Joint stability
Swimming equipment[20,41] (excessive use of pull-buoys, hand paddles, kick boards, fins)	Biomechanics
Swimming technique (poor technique)	Hypermobility
Dry-land training[84] (poor supervision and inadequate provision of age-appropriate programme)	Reduced fitness level

2.6.2.1 Unique anatomy and physiology

a) Growth spurt and non-linearity of growth

During the adolescent growth spurt, linear bone growth exceeds bone mineralisation; bone is more porous and soft[12]. The rate of long-bone growth also exceeds growth of surrounding muscles and tendons[58,92]. This causes an imbalance around joints resulting in muscle-tendon tightness, reduced flexibility and reduced physeal strength[12,33,58]. The growth-plates (physes) have not yet fully closed and the epiphysis is still developing. Excessive stress in the form of physical activity negatively affects these structures, causing physeal, apophyseal, and bony stress injuries[93]. Tendons, exhibiting increased tensile strength, attach to the bone at the apophysis. Tension stresses and traction from tendons may cause disruption at the cartilage-bone junction during periods of rapid growth, resulting in apophysitis. Strains at the apophysis are more common in early adolescence, whereas muscle strains are more common in late adolescence[50]. The most common areas of apophysitis are: insertion site of the patella (Osgood-Schlatter disease); Achilles tendon insertion (Sever's disease); origin of the wrists flexors at the medial epicondyle (Little League Elbow)[36]. Section 2.5.1 (page 24) mentioned shoulder and knee injuries as the most common injury sites due to the repetitive nature of swimming training itself.

The risk of injury to these joints is further exacerbated in young swimmers by the previously mentioned adolescent-associated imbalances in bone, tendon and muscles. Therefore, the unique anatomy and physiology of adolescents combined with rigorous training regimes has the potential to increase risk of injury further.

b) Maturity associated variation

Athletes of the same chronological age vary in their body size and stature. During contact sports like football, ice-hockey and rugby these differences in physical maturation place weaker and smaller adolescents at increased risk. Thus, having increased strength positively influences the outcome of the game[12]. In gymnastics or long-distance running, however, increased height and weight could be deleterious to the individual and subsequent success achieved. These adolescents, with increased body mass indices, produce greater forces which in turn are absorbed by the joints and soft tissues, potentially accelerating injuries[12]. Therefore, it seems size recommendations are often sport specific. In swimming competitions, individuals are usually grouped according to chronological age irrespective of height, weight or strength differences. Morais et al.[74] evaluated the effects of anthropometrics on swimming performance in water polo players[74].

It was found that taller players with larger surface areas had improved swimming performance compared to smaller counterparts. In another study of adolescent swimming performance, Lätt et al.[39] found anthropometrical and physiological parameters account for 46% and 45% of swimming performance indicators respectively[39]. McKenna et al.[22] found that a larger body mass index correlated with shoulder injury incidence in adolescent swimmers[22].

2.6.2.2 Age

Injury risk consistently displays a linear relationship with age across studies. Injury rates appear to be higher in adolescent athletes (> 12 years) relative to paediatric athletes. Increasing age runs parallel with increasing levels of competition, body size and exposure times, which are further thought to increase adolescents' injury risk[11]. The relationship between age and injury rates in some cases is sport specific when considering the amount of skill required. In comparative injury surveillance studies, some authors found adolescent's aged 10 to 14 years to be at greater risk, whereas others discovered those aged 15 to 19 years were at greater risk[42]. In these studies differing aspects of the relationship between injury risk and variables were investigated. This makes comparison between age and varying sport types almost impossible. Wolf et al.[29] found that male distance swimmers sustained more injuries during their study compared to female distance swimmers[29].

Another study investigating the injury incidence in adult swimmers found that females sustained more injuries than men but the difference was not statistically significant[30]. Tate et al.[42] investigated shoulder injuries in adolescent swimmers, and found those aged 15 to 19 had the highest injury incidence[42].

2.6.2.3 Gender

Some authors found overall injury rates in adolescent girls and boys to be similar across a variety of sports[34]. Others argue that males are at increased risk compared to females (ratio of 2:1)[11,33]. This differing opinion may be attributed to the type of sport investigated (contact or non-contact), larger body mass of males or suggested increased aggression[11]. Interestingly, authors concur that concussions, fractures and bleeding injuries are more common in boys; ligament injuries and muscle strains more common in girls[12,33,34]. Two swimming studies investigating overall and joint specific injury incidence found no significant differences between genders in adolescent and adult swimmers[29,38]. A study evaluating swimmer's shoulder in participants aged 12 to 23, found females to be at increased risk of suffering an overuse injury[41]. There was no difference in training regimes between genders so the increased risk was attributed to females' shorter arm strokes. Shorter arm strokes relative to men, result in more female arm strokes having to be performed across the same distance, leading to overuse[20,94].

2.6.2.4 Training exposure duration and distance

Consensus exists in that increased hours of training, especially the added pressure of competition, result in greater injury rates[11,21,34]. High exposure levels during this period of major physiological change in adolescents is a significant risk factor[50]. Literature considering swimming and other sporting injuries consistently reports that the relationship between activity exposure and injury risk is linear (i.e. directly proportional to one another)[6,26,27,95]. Increased number of athletes, programme-compliance and the ability to oversee a training session make it unfeasible for coaches to tailor-make training programmes for swimmers at high-school club level. For this reason the principle of specificity is poorly applied because adolescent athletes of the same team usually complete the same training sets. While this is the more practical option, it fails to take into account individualised intrinsic risk factors. In short, what is an acceptable programme for a swimmer of certain stature may lead to 'over-load' in another of smaller stature and joint imbalances.

Numerous studies evaluating competitive swimming exposure provide information regarding training volumes for adults. During extensive training periods, swimmers are known to practice five to seven days a week and often twice daily[42]. In a two-hour training session, competitive swimmers may cover between five and seven kilometres (km)[94]. Therefore, bi-daily sessions result in distances ranging from 7-18 km per day. Hence, it is derived that weekly swimming distances range from 9 km at club level[27], from 50-65 km at elite level[94], to 110 km at international levels[27]. This results in athletes swimming a minimum of 20 to 30 hours per week[20,30]. Literature states that competitive swimmers start their careers as young as six to seven years old[8,21,92,94]. Hence, by the time young swimmers reach adolescence it is thought that their training regimes are similar to those of adults[29,47]. A study interviewing 97 swim coaches from different clubs throughout the United States of America found that swimmers aged 11 to 14 trained approximately 5 to 15 hours per week and swam less than 23 km[84]. Swimmers aged 15 to 18 trained 11 to 20 hours per week and training distance ranged from 23 to 37 km per week[84]. Competitive swimmers complete approximately 2 500 stroke revolutions per arm per training session[83], resulting in an excess of 500 000 freestyle stroke revolutions each year[8,14,94]. Females, having shorter strokes, perform an extra 660 000 stroke cycles annually[20,94].

2.6.2.5 Parents and coaches

A survey of elite young athletes found that parents were extremely influential in the initiation of their child's sport especially with regards to swimming, tennis, gymnastics and soccer (early specialisation)[21]. The parents' active participation in the sporting process coupled with a child's will to please its parents is assumed to add immense pressure in achieving success[90]. Coaches assume this role from the parents and are responsible for guiding training sessions. Given that exposure contributes substantially to injuries, 'overexposure' as prescribed by coaches is largely responsible for increased injury rates[90]. Inexperienced or overly ambitious coaching could result in excessive distance completed per swim session / season, incorrect order of pull or kick sets or poor demonstration of drills, thus elevating levels of extrinsic risk.

Anecdotally, coaches driven by personal gains are thought to push boundaries when it comes to training. Successful athletes are representative of a successful coach, club and team. One could assume that coaches' determination to succeed may be to the detriment of athletes'. This added pressure, from parents and coaches, to achieve success may be an additional psychological risk factor in adolescents.

2.6.2.6 Early specialisation

Early specialisation refers to participation in exclusively one sport, thus attempting to maximise potential for success[21]. The increased size of the global young-athletic-population has steered international-level competition towards beginning at the ages of six to eight years old[12]. This "*catch them young*[70(p130)]" principle suggests, that international success at senior levels can only be achieved if training is commenced at pre-pubescent ages. This early specialisation trend is particularly evident in swimming. Young swimmers demonstrating significant potential are dissuaded from partaking in other sports in order to develop their water skills more rapidly. Hence, by the time these young athletes reach adolescence, they have already undergone extensive training at high competition levels for numerous years[70]. There is much controversy regarding this topic.

Whilst sound evidence validates the early specialisation approach[92], research in athletes has not consistently demonstrated that this approach achieves elitism and negative consequences have been associated with its implementation. Adolescent athletes, going through stages of empirical biological development, may experience dire physiological consequences at very young ages as a result of excessive training[92,96]. It can be argued that fewer years spent training reduce the risk of overexposure resulting in fewer swimming injuries (Section 2.6.2.4, page 30). Recent surveys have shown that many world-class, international athletes only started specialising in late adolescence and spent fewer hours concentrating on only one sport before the age of 15[21]. Swimmers who specialised early, spent less time on a national team and retired earlier than those who specialised later[97]. Lack of enjoyment was quoted as a significant contributor to early retirement from competitive sport[21,92].

2.6.2.7 Previous injury history

Studies unequivocally denote that previous injury is a significant risk factor for future injuries as it increases risk by up to two and a half times[11,32,34,51]. Previous injuries can cause fibrosis resulting in adhesions and reduced range of movement (ROM) at a joint[12]. These factors predispose the area to further injuries at the same site due to ligament laxity, reduced muscle strength and poor proprioception. Other areas may also be indirectly affected as reduced ROM and consequent muscle atrophy at one joint may result in a compensatory mechanism at another. An estimated 47% of injuries in adolescents are attributed to re-injuries in sport[34]. This highlights the need for screening and perhaps subsequent rehabilitation programmes in adolescent populations.

2.6.2.8 Muscle strength

Literature demonstrates that changes in activity and strength in the rotator cuff and scapular stabilising muscles significantly increase risk of shoulder injury in overhead athletes[20]. Studies investigating overhead athletes have consistently found that discrepancies in shoulder rotation strength and scapula dyskinesis are risk factors for sustaining shoulder injuries[20,26,41,79,98–100].

2.6.2.9 Hypermobility

Authors investigating sports injuries in adolescents across a variety of sports have found generalised joint hypermobility to be a risk factor for future injuries in young athletes[101,102]. Increased glenohumeral translation (hyperlaxity) was found to be a risk factor in many studies evaluating shoulder injuries in swimmers[20,79,103]. It is still debated, whether the hyperlaxity results from generalised joint hypermobility or rather from acquired labral degeneration due to the stroke cycle[79]. Interestingly, hyperlaxity of the shoulder was found in both symptomatic[20] and asymptomatic swimmers[79]. Instability is thought to be a symptom of hyperlaxity in the shoulder joint.

2.6.2.10 Equipment and technique / skill

Most sporting rules and regulations (encompassing equipment used, field surface area size and length of match-play) have been developed specifically for adults[33]. This means that sports parameters generally, are not adjusted to the size of younger participants. This provides a distinct disadvantage and places them at increased risk of injury. General examples of this would be the standard height of volleyball nets / basketball hoops and size of soccer / rugby fields.

In swimming, the high construction and maintenance costs make it unrealistic to build pools of smaller sizes. Therefore, pools have standard pool sizes of 25-or 50-m. This means that skeletally immature adolescents train and compete against each other in the same-sized pools as adults. An adolescent's smaller stature means the number of stroke cycles performed to achieve a 100-m distance may exceed that of an adult for the same distance. The possible increase in stroke cycles could be a potential risk factor and advocates training volumes be adjusted to suit adolescent needs[74]. Training and competition output of adult elite swimmers in standard pools is monitored frequently to improve performance[74]. Anecdotally, it is thought that young swimmers do not always have the same kind of monitoring. Lack of monitoring could be a further potential risk factor for injury. Some swimming studies found the use of hand paddles, pull buoys and kickboards to aggravate already existing injuries[20,41].

This swimming equipment may also potentially increase risk in swimmers who have not yet sustained an injury. As yet, no control study has investigated the relative risk of equipment versus no-equipment use.

Injuries also result from incorrect technique or deficient skill sets. The glenohumeral joint experiences greater stresses during different points in the stroke in inefficient swimmers which causes degeneration when combined with the repetitive nature of training[104]. Developing technique for sport requires hours and years of practice. Adolescents are at a distinct disadvantage by virtue of their young age meaning fewer years to practice perfecting swimming technique[36,33]. Some motor skills and fine-tuning of dexterity can also only be developed with a skeletally mature system. The consequence of improving skills, however, is that adolescents are then required to perform at higher levels of competition. Higher competition has already been established as a risk factor in swimmers.

2.6.2.11 Dry-land training

Dry-land training is endorsed by many swim coaches and is an important supplement to swimming training[1084]. It is performed by most swimmers at some point in their swimming careers[84]. Larger volumes of dry-land and cross-training occur in the off-season or when competition volumes are lower[29]. Krabak et al.[84] found that the main reason for dry-land training in younger swimmers (10 to 18 years) was injury prevention, whereas masters swimmers (18 years or older) completed dry-land sessions to enhance performance components like power, strength and speed[84].

Despite dry-land training forming an integral part of swimming training, no guidelines exist regarding the type, frequency and intensity of exercises that should be included to establish an ideal programme[84]. Literature on the benefits of dry-land training is conflicting, further making it difficult to compile standardised programmes. Some authors found dry-land training to positively influence performance indicators[105,106], while others determined no benefit[10,107]. It appears that amount of dry-land training participation amongst adolescent swimmers is directly proportional to age; the older the swimmer, the more dry-land training completed up to collegiate levels[84]. Despite this, again information regarding the age at which swimmers are to begin with dry-land sessions is scarce. Studies investigating injury incidence in collegiate swimmers found that dry-land training contributed 38% to 44% to all swimming injuries[29,108].

2.7 OPERATIONAL DEFINITIONS AND MEASUREMENT INSTRUMENTS

Risk factors known to increase injury incidence in adolescent swimmers were discussed in detail in Section 2.6.2. Further risk factors, which have the potential to increase swimming injury susceptibility which will be evaluated in this study, include: reduced or asymmetry of muscle strength, joint hypermobility and glenohumeral internal rotation deficit (GIRD). Previously, various measurement instruments were implemented to evaluate these factors. For the purposes of this study the following measurement instruments will be used: the Baseline questionnaire, Injury report and training questionnaire, Beighton score[109], hand-held dynamometer muscle strength measurements[110,111] and glenohumeral internal rotation deficit[112] (GIRD) measurements. In injury surveillance studies, definitions provide standards for recording and comparing inter-study results[2]. Hence, in the sections that follow it is imperative that operational terms be defined whilst measurement instruments are elaborated on.

2.7.1 Definition of terms relating to injuries

The first word that necessitates definition and clarification is 'injury'. Obtaining clarity proves challenging, since no consensus exists as to what constitutes an injury[2,7]. An injury occurs as a result of *"bodily damage caused by a transfer or absence of energy*[2(p329)]*"*. This definition was derived from a previous definition by the National Electronic Injury Surveillance System All Injury Program (NEISS-AIP), which declared that damage ensued from an external substance or force[7]. This definition, however, excluded both injuries without an identifiable cause and those that are non-physical[7], hence necessitating revision. Historically, surveillance studies explored predominantly catastrophic injuries such as concussions and defined injuries as occurring in the face or head regions only[50]. Recently, authors have expanded research to include even minor tissue damage (lacerations or bruises) in the definition of injuries[7].

Next, it is important to differentiate between injuries that could be medical or health-related, and sports injuries. A sports injury is said to be related to and sustained during a particular sporting activity[5,7]. These injuries interfere with sport participation because athletic activity is modified and often ceased as a result[65,66]. Some authors insist that an ailment only constitutes a sports injury when the need arises for assessment by a medical professional. Others dispute this, in that not all athletes with injuries require or have access to medical intervention, yet a day of missed practice is needed to allow time for healing to occur.

In summary, sports injuries appear to have three mutually exclusive yet widely accepted definitions: 1) injury sustained during or as a result of participation in organised practice or competition[7,66]; 2) injury that requires intervention from a medical professional[4,17,65,66]; 3) an injury resulting in partial or complete restriction of athletic participation for one or more days[4,7,17,50,65,66,113].

Much of the global injury data reflects only the frequency at which injuries occur, but does not provide information about the severity of injuries. For this reason consensus statements relating to sports injury definitions should provide information about 1) time spent away from sport participation (time-loss) and 2) injury severity[7]. Time-loss is measured in days as is shown in Table 2.5[2,3]. The length of time-loss differs, depending on aspects such as injury severity, pain perception, individual healing time and an athlete's compliance with treatment[29,30]. Measurements of injury severity follow two trends. Some studies measure injury severity by time-loss from full sport participation. The measurement is taken from the first day post sustaining the injury[3] until the athlete once again returns to full participation in training or competition. The amount of days missed are further classified as slight, minimal, mild, moderate and severe as can be seen in Table 2.5.

Other studies regard severity as a completely separate entity, meaning it is judged by its catastrophic potential, regardless of time-loss. The catastrophic potential is directly proportional to the amount of tissue damage and includes nerve, dental, eye injuries and concussions as examples. The Abbreviated Injury Scale, as depicted in Table 2.6, is often used in studies where time-loss and injury severity are classified separately. Irrespective of which definitions are used, the higher the injury severity, the greater the priority allocated to preventing future occurance[7].

Table 2.5: Injury severity measured in time-loss[2,3]

Severity	Time loss (days)
Slight	0 – 1
Minimal	2 – 3
Mild	4 -7
Moderate	8 – 28
Severe	> 28

Table 2.6: Abbreviated Injury Scale

Severity	Score
Minor	1
Moderate	2
Serious	3
Severe	4
Critical	5
Lethal	6

The mechanism of injury provides clinicians with useful information about injury origin. An acute injury occurs due to a specific identifiable event. This means the onset of injury was sudden and the cause is usually known. Chronic injuries, also termed overuse injuries, have no traumatic onset or identifiable event. Their onset is insidious, usually as a result of repetitive micro-trauma to an area of the body.

Acute or overuse mechanisms of injury result in an 'index injury'. An index injury is the first injury to transpire within a given study period[17]. A 'recurrent injury' occurs subsequent to the first injury and has the same location and type as the index injury[17]. Recurring injuries make up 10% to 25% of all injuries and are often more extensive than the initial injury[17]. They also play a role in athletes' ceasing sport participation[17].

The definition of a sport's injury further encompasses words like 'nature', 'injury location' and 'type'. The nature of injuries provides an overview and incorporates many terms to give an accurate description of injury status. 'Injury nature' therefore includes: location, type, body side injured, and index or recurrent injury. The injury location is represented by a certain body part and refers to the anatomical region the injury is located in. The 'injury type' investigates injury location a bit further.

It assesses both specifically injured structures (i.e. bone, muscle, joint, ligament, tendon, skin and central or peripheral nervous system), and describes the dysfunction in terms of fractures, tears and strains to name a few. Table 2.7 is an amalgamated table compiled by Fuller et al[3]. and depicts the main groupings and categories for the classification of injury location and type. The original tables were published in a consensus statement for injury definition and data collection procedures of studies of soccer injuries and used in accordance with the Orchard Sports Injury Classification System (OSICS)[3].

Table 2.7: Classification of injury location and type[3].

Injury location		**Injury type**	
Main grouping	**Category**	**Main grouping**	**Category**
Head	Head / face Neck / cervical spine	Fractures and bone stress	Fracture Other bone injuries
Upper limbs	Shoulder / clavicular Upper arm Elbow Forearm Wrist Hand / finger / thumb	Joint (non-bone); Ligament	Dislocation / subluxation Sprain / ligament injury Lesion of meniscus or cartilage
Trunk	Sternum / ribs / upper back Abdomen Lower back / pelvis / sacrum	Muscle and tendon	Muscle rupture / tear / strain / cramps Tendon injury /rupture / tendinosis / bursitis
Lower limbs	Hip / groin Thigh Knee Lower leg / Achilles tendon Ankle Foot / toe	Contusions Laceration and skin lesion	Haematoma / contusion / bruise Abrasion Laceration
		Central and peripheral nervous system	Concussion (with or without loss of consciousness) Nerve injury
		Other	Dental injuries Other injuries

There is further disparity concerning the definition of 'fully healed injuries'. Two definitions of the term appear to be widely accepted. Some authors consider an injury healed from the date of return to play (RTP). This is met with contention because RTP can vary significantly, depending on both the injury location and the sport. For example, a lower limb injury would prolong a track-and-field athlete's RTP, whereas an upper limb might not. Similarly, athletes may be inclined to RTP sooner if a big competition is imminent or if they have a high pain tolerance. The second accepted definition states that an injury is fully healed if athletes have attended their last treatment session. This follows the premise that treatment would not continue should the nature of the injury still necessitate it.

According to Goldberg et al.[7] there are three main issues which demand consideration when designing an injury surveillance study: the definition of a sport's injury; the tool of injury reporting; and the process of data collection[7]. The first issue has now been described. The second and third essential components of an injury surveillance study will be unravelled in the text that follows.

2.7.2 Measurement of injury incidence (modified Injury report and training questionnaire)

Increases in the swimming population size globally and hours spent swimming are correlated with rises in swimming injury incidence[26]. Measurement of injury incidence is a valuable outcome measure because this is the most basic expression of risk[12]. Previous studies have found the measurement of incidence via injury report forms to be valid and reliable[33], yet sports injury research is challenged by the absence of a universal injury reporting tool[7]. Standardised injury report forms (including training exposure sections) exist predominantly for popular land-based sports like soccer, rugby and cricket. Few authors have addressed the epidemiological considerations of injury surveillance studies in swimming in particular. Those that have, evaluated the incidence of injuries only in adult swimming populations and the land-based report forms necessitated swimming-specific modification.

Additionally, injury surveillance studies in sports predominantly rely on retrospective reporting[29,114]. Some recent studies demonstrating prospective reporting in swimmers were once again limited to injuries sustained by adults during a collegiate season or international competition[29,30,41,43,115]. Furthermore, these swimming studies investigate specific injury types and locations only, thus focussing typically on only one joint (i.e. the shoulder).

Authors investigating adolescent injury incidence in sports such as soccer, hockey and rugby had to modify adult questionnaires. Consequently, current report forms pose two problems: no standardised injury report forms exist for swimming exclusively or exclusively for adolescents partaking in sport. Literature has yet to combine the two subgroups of swimming and adolescents; none have investigated the correlation of potential risk factors with incidence in a competitive adolescent swimming population over a six-month period.

Walker et al.[41] investigated swimming shoulder injury incidence in a population aged 11 to 27, which includes the current studies' adolescent age group[41]. Hence, a similar version of Walker et al.'s[41] report form will be used and modified to encompass the entire body[41]. The Injury report and training questionnaire consists of both injury incidence and training exposure sections (Appendix 2).

Previous swimming injury studies also used questionnaires/surveys and similar information was obtained. The injury section of the current report form includes: injury location, type, body side, mechanism of onset, new or recurrent injury and severity. The training exposure section includes a log of the number of days spent training and competing along with the level of difficulty (expressed as rate of perceived exertion). Since participants are still in school and likely to partake in sports other than swimming, evaluation of land-based school sports and dry-land training will also be included in exposure.

Since the study investigates adolescents it is important to simplify the report form to enhance compliance. Other studies investigating injury incidence in adolescents have simplified information regarding injury location and type. Moreover, the type of injury is often diagnosed by a medical professional. High-school or club level sports rarely have medical professionals on hand to make such a diagnosis. It can be assumed that coaches also lack the clinical expertise required to make an accurate diagnosis. Thus, injury-type documentation will be omitted from this study, only allowing for descriptions of injury locations. From the weekly completed report forms the injury incidence and athletic exposure can be calculated.

2.7.2.1 Injury incidence rate

Injury incidence rate refers to the ratio of injuries incurred within a specific time frame of sports participation. The rate is calculated by means of "denominators", without which only injury frequency can be calculated[7]. These denominators are: total number of participants, total number of matches or training sessions, total number of player hours (athletic exposures). Thus, injury incidence rates can be documented as a) injuries per participant per season / year, b) injuries per match or practice exposure or c) injuries per athlete-hour of exposure[7]. An example of the calculation is depicted below as the number of injuries per athletic exposure, per 1000 player hours[3]:

[Σ injuries / Σ exposure hours (AE's)] × 1 000[3]

2.7.2.2 Athletic exposure

Athletic exposure (AE) is a measure of the time spent by an athlete partaking in a particular sport. This means one athlete partaking in a single game or practice session[4,17,30]. In swimming, one AE would refer to an individual swimmer participating in one pool training session, irrespective of the length of time or distance covered in that training session. To better evaluate the varying contexts of participation, is it necessary to split the denominator into competition- and practice-exposures[7].

Previously, scarce information existed regarding incidence per hours of training or athletic exposure[4,30]. For this reason, injury rates were commonly documented as clinical incidence, meaning injury prevalence per 100 participants[30]. This ratio estimates the probability of an athlete being injured in a season, however, fails to take into account differences between individuals which potentially affect injury susceptibility[30]. Recently, more studies are leaning towards documenting injuries per 1000 hours of exposure[7,30,70,114]. This beneficially provides insight regarding individual athlete characteristics and risk factors[7]. Using AE's also standardises the relative risk and allows for comparison between sports, genders, ages and locations.

2.7.2.3 Modified Borg scale

Rate of perceived exertion (RPE) can be measured using the modified Borg scale[116], a valid and reliable tool[117,118]. The 11 point scale, ranging from zero to ten, quantifies perceived exertion as an indicator of physical strain and can be applied by adolescents[116,118].

2.7.3 Measurement of individual athlete profile (Baseline questionnaire)

Walker et al.[41], used the Prospective study questionnaire in their study and had it tested for reliability[41]. The study mentioned it was found to be suitably reliable for swimming research purposes[41]. Thus, the skeleton of the same questionnaire will be administered during baseline testing of this study. The prospective questionnaire consists of 19 questions divided into separate subsections: A) demographic profile, B) competition profile, C) training profile and D) injury profile. All questions are straight forward, requiring only single words, numbers or ticks as answers and are easy for adolescents to complete. Other studies concur by asking the same or similar questions in their baseline questionnaires.

Section A comprises documentation of height, weight, hand dominance, years spent swimming, breathing side dominance, and age at which the participant started competing. For purposes of the current study more demographic information is needed to meet the objectives. Therefore age; gender and body mass index (BMI) will be added.

Previous studies evaluating the effect of anthropometry on adolescent sporting performance or injuries, have also recorded demographics in baseline testing. Section B and C include information regarding stroke preference, level of competition, personal best times, average time and distance in training, paddle use, stretching and dry-land training. Section D is further subdivided into three parts. Part one evaluates injuries of the last 12 months. It entails details of injury location, resultant activity modification, body side and preventative measures taken. Part two assesses activity restriction of a specific injury over the last 12 months. Part three evaluates current pain and activity restriction on the day of baseline testing. The nature of the current study necessitates that small amendments are made to section D; the injury profile will be expanded to include all injuries.

2.7.4 Measurement of hypermobility (Beighton Score)

Generalised joint laxity (hypermobility), is a hereditary condition in which most synovial joints have increased range of motion (ROM)[119–121]. This increased ROM exceeds the range deemed normal for any given joint[119] and is more prevalent in children, adolescents and females[119–122]. Literature states that athletes with joint hypermobility are at increased risk for sustaining musculoskeletal injuries[101–103,119,122–124], particularly during sports activities[101,103,124]. It has been found that competitive swimmers require increased shoulder mobility to enhance swimming technique[103]. While excessive ROM allows swimmers to perform more powerful strokes, it negatively affects joint stability in that supporting structures may be stretched.

From this we derive that there is a fine balance between increased mobility and instability[103].Since this study investigates injuries and possible risk factors in an athletic adolescent population, it is appropriate to measure hypermobility as a possible risk factor[101,103,124,125].

The Beighton score (BS) (Appendix 3) is the index most commonly used to quantify joint mobility[103,119–121,125]. Table 2.8 provides a brief summary of some studies measuring joint hypermobility using the Beighton Score. Detailed evaluation of studies is provided in Appendix 4 (Table A). The index consists of five clinical manoeuvres: fifth finger extension, elbow extension, knee extension, wrist flexion with opposition of the thumb towards the forearm, trunk and hip flexion[101,103,109,119–122,124,125]. Barring item five, all of the movements will be examined bilaterally and must have pain-free ROM. Assessment of items one to three will be performed using a goniometer[109]. Passive ROM will be assessed in items one to four. In this study, the standardised joint mobility protocol will be used[109,120]. This includes description of anatomic landmarks, goniometer placements, starting positions and test motions.

Each of the five manoeuvres are scored dichotomously (0/1)[120,122]; a score of zero is awarded to negative values and a score of one to positive values[123]. Positive values indicate movement beyond the standard values[125] for the joint being measured. Items one to four may receive a maximum of two points per item if both right and left sides are positive. A maximum of one point may be awarded to item five. The Beighton score total ranges from zero to nine point-values. Total scores are divided into three categories (zero to two, three to four, five to nine), with greater scores indicating greater joint hypermobility[119,123].

The cut-off point to determine hypermobility is internationally debated[109]. Most literature quantifies hypermobility as total scores of ≥ four in adults[101,121,123,124] and ≥ six[109,122] in children. There is no finite value correlated with hypermobility in adolescents, but some studies have classified hypermobility as scores of ≥ five[102,120,125,126] for this population. Hence, the same value (≥ five) will be used in this study.

The BS has well-established validity and reliability in both sedentary and athletic populations of all ages[101,109,119,120,124,125]. Both inter- and intrarater reliability are deemed good to excellent[119]. It was suggested that routine screening of athletes for joint laxity should be conducted to implement prevention programmes[124]. The BS is easy to administer, cost-effective (requires only the use of goniometers) and can be completed within only a few minutes[109].

2.7.5 Measurement of muscle strength in shoulders and knees (hand-held dynamometer)

Literature states that the most common swimming injuries occur in the shoulder[8,14,20,22,26,30,41,66,72,79,86], spine[27,29,30,43] and knee[27,29,75,77]. Studies evaluating swimming injury incidence in adults have found imbalances between internal-and external rotator shoulder muscle strength positively correlate with injuries. No literature evaluating injury incidence of a pure adolescent swimming population was found. Thus, future descriptive epidemiological studies necessitate documentation of many possible risk factors. For this reason muscle strength of shoulder and knee joints will be measured to determine any correlation between deficits or asymmetries and injury incidence in an adolescent swimming population.

The hand-held dynamometer (HHD) is a portable device used to measure isometric muscle strength. It is superior to manual muscle strength testing[127] due to its accuracy in measuring force[111,128]. Table 2.8 provides a brief summary of some studies measuring muscle strength using a hand-held dynamometer. Detailed evaluation of studies is provided in Appendix 4 (Table B). Isometric strength of shoulders and knees should be assessed bilaterally. Assessment of five common shoulder actions include: elevation (pectoralis major, anterior deltoid, long head of biceps brachii, coracobrachialis muscles[129]), hand behind back lift-off (subscapularis muscle[130]), horizontal abduction (supraspinatus, middle deltoid muscles[129]), external rotation (teres minor, infraspinatus, posterior deltoid muscles[129]) and internal rotation(subscapularis, teres major, latissimus dorsi, pectoralis major, anterior deltoid muscles[129])[42,99,100,128,131]. In accordance with methods used by previous studies, knee flexion (hamstrings, gastrocnemius, gracilis, Sartorius and popliteus muscles) and 2) extension strength (quadriceps femoris) will be determined in a seated position[132–137].

The classic lift-off test (Gerber's test[130]) determines the presence of subscapularis tears or dysfunction[58,129,130]. Therefore, measuring strength produced during the lift-off test assesses subscapularis muscle strength. Subscapularis is a rotator cuff muscle, with an important role in centring the humeral head in the glenoid fossa[129]. It is arguably the most powerful internal rotator of the shoulder joint. Any weakness of this muscle allows the humeral head to displace upwards, creating greater opportunity for shoulder impingement and resultant pathologies[129]. In the recovery phase of the freestyle stroke, the upper limb is mostly in external rotation. On hand entry it should be neutral and only begin internal rotation once the greater tubercle has cleared the acromion process[104,138].

This mechanism, however, often causes a faulty technique where swimmers internally rotate the arm too soon. Hence, the thumb enters the water first on hand entry. This is thought to increase the risk for shoulder injury[104,138].

In previous studies, participants were required to work up to their maximum voluntary contraction (MVC) against resistance over one to two seconds, then sustain this contraction for a further four to five seconds[128,136,139]. Two familiarisation trials were done followed by four actual measurements[127,139]. A rest period of 30 seconds was given between each of the four measurements and the highest value recorded to one decimal point. The verbal cue of "*go ahead –push-push-push-push and relax*[110(p552)]" was used. Thorborg et al.[110] found that this method of measurement could be performed by testers of different sex without systematic bias[110].

Shoulder rotation and horizontal abduction starting positions will be performed in prone (Table 3.3), in accordance with Tate et al.[42] and Nodehi-Moghadam et al.[100] who also assessed swimming populations[42,100]. Prone lying is functional for swimmers and produces the highest torque values[42]. Shoulder elevation and behind the back lift-off positions will be adopted as per Hayes et. al[128]. Knee flexion and extension will be performed in sitting, as described by Kollock et al.[136] and Koblbauer et al.[137] (Table 3.3). Due to the force exerted by a MVC, the movements will be resisted by means of an adjustable strap.

The strap will be altered to remain perpendicular to the leg throughout the movement and ensure 90° knee flexion. In extension, the strap is secured to a pillar of the plinth and in flexion around the assistant's leg. The strap further helps secure the HHD in place to prevent shifting. Thorborg et al.[110] found the inter-rater reliability of using a HHD with an external belt fixator to be acceptable[110]. Shin guards, also used in a study by Koblauer et al.[137], aim to reduce discomfort from HHD placement and allow for standardisation of HHD position[137]. Participants need to place hands (palm up) in their laps to prevent compensation[16].

A systematic review describes the HHD as easy to use, cost effective, portable and compact[127] and comments that HHD validity has been established in literature[127,140,141]. The tool has moderate to good reliability when compared with the gold standard of isokinetic testing[127]. Intra- and interrater reliability is described as good to excellent [110,111,128,132,136,137,142] making it a suitable for use in this study.

2.7.6 Measurement of shoulder internal and external rotation (total arc of motion and glenohumeral internal rotation deficit)

It is known that changes in shoulder internal and external rotation are positively related to shoulder pathology[15]. The total arc of motion (TAM) is measured by adding the values of glenohumeral external rotation and internal rotation together[23]. Literature suggests that in athletes participating in overhead sports, the TAM of the dominant arm shifts into more external rotation and less internal rotation[2315,23]. Although swimming is a bilateral sport, it is suspected that more force is exerted through the dominant limb[16]. Total arc of motion deficit (TAMD) is the difference in TAM between dominant and non-dominant sides[23]. Current research places the TAMD threshold at a 5° difference between sides[23,143].

Previously, it was believed that the loss of internal rotation results from anterior instability of the shoulder joint due to continuous stretching of the inferior glenohumeral ligament during overhead sports[16]. In opposition to this, Burkhart et al.[15] proposed that excessive external rotation with horizontal abduction results in stretching of the anterior structures of the shoulder joint[15]. This leads to the tightening and contracture of the posterior capsule with an acquired loss of internal rotation of the glenohumeral joint[15,16]. This phenomenon is called glenohumeral internal rotation deficit (GIRD). GIRD is defined as the loss of glenohumeral internal rotation (GIR) of the dominant versus the non-dominant arm[15,16,23,112,143,144]. GIRD is said to be a risk factor for sustaining shoulder injuries because it results in alteration of shoulder joint biomechanics[143]. Table 2.7 provides a brief summary of some studies measuring GIRD in overhead athletes. Detailed evaluation of studies is provided in Appendix 4 (Table C). Some studies have shown that a GIRD as little as 11° can predispose the shoulder to injury[112]. In sports with overhead activity, like swimming, GIRD is said to increase and glenohumeral internal rotation decrease with time[16,143]. Screening for GIRD and TAMD in swimmers may prove valuable because both have been linked to injury pathophysiology and are thought to increase throughout an athletic season[14–16,143].

Burkhart et al.[15] first described a standard measurement procedure and other authors have since followed suit, implying consensus[15,16,23,112,143,144]. Patients lie supine with the test shoulder in 90° of abduction and 90° of elbow flexion[15]. Two testers are required to complete the measurement; one stabilises the scapula and performs the rotation movement whilst the other measures[15]. Goniometric measurements of 1) glenohumeral internal rotation, 2) glenohumeral external rotation and 3) total arc of motion are recorded for each participant. Torres et al.[16] measured the left shoulder first regardless of hand dominance[16].

The same will be done in the current study. GIRD and TAMD measurements are easily administered, cost effective and take less than five minutes to complete. GIRD measurement was found to be highly reliable with test re-test reliability of 0.92[143].

Table 2.8: Brief summary of measurement instruments used in child and adolescent cohorts

References	Participants	Tested in adolescent population	Cut-off scores	Key aspects of application	ICC	Conclusion
			Beighton Score			
Boyle et al.[119]	Non athletic: 42 intrarater 36 interrater	Yes	≥ 5	Test conducted with subjects standing (except knee hyperextension)	--	Reliability of BHJMI good to excellent Reliability of composite scores Intrarater: 69% agreement Spearman rho 0.86 Interrater: 51% agreement Spearman rho 0.87
Cameron et al.[123]	714 Freshman Class United States Military Academy 630 males 84 females	Yes	≥ 2	Clinical measurements performed by same sports medicine orthopaedic surgeon	-	GJH and history of glenohumeral joint instability are related
Jansson et al.[103]	120 competitive young swimmers 1277 matched controls	Yes	-	Children performed own test movements without pain	-	Compared to controls: Male swimmers had higher general joint laxity Female swimmers had lower laxity Competitive swimming causes ↓ shoulder rotation
Smits-Engelsman et al.[109]	551 school children	Yes	≥ 7	Movement demonstrated by tester and performed painfree	0.99 between first and second measurement	BS is a valid instrument to measure GJH in children
Smith et al.[102]	200 female netball players	Yes	≥ 5	BS measured after warm-up and applied by	-	Hypermobility is significantly associated with increased prevalence of injuries in junior netball players

Key: - Not mentioned; SEM – standard error of the mean; ICC – intraclass correlation coefficient, r – correlation coefficient, BHJMI – Beighton and Horan Joint Mobility Index, HHD – hand held dynamometer, GIRD – glenohumeral rotation deficit.

Table 2.8: Brief summary of measurement instruments used in child and adolescent cohorts continued.

References	Participants	Tested in adolescent population	Cut-off scores	Key aspects of application	ICC	Conclusion
			Hand-held dynamometer			
Roy et al.[140]	38 volunteers	No	-	Isometric shoulder strength tested while seated	-	HHD valid for determining isometric muscle strength r: 0.81 – 0.93 95% Cis 0.66 - 0.92
Kollock et al.[136]	37 college under-graduates	No	-	Isometric strength hip and knee strength tested seated and standing	Intrarater reliability 0.70 - 0.94 Interrater reliability 0.69 - 0.91	Good to high intra- and intersession reliability for HHD SEM 1.72 – 13.15 N)
Stark et al.[127]	17 manuscripts	No	-	Muscle testing of shoulder, elbow, knee, hip and ankle	-	HHD can be regarded as a reliable and valid instrument for muscle strength assessment in a clinical setting
			GIRD			
Myers et al.[112]	11 competitive baseball players 11 matched controls	No	-	Test position supine with elbow in 90° abduction	-	Throwing athletes had significantly greater GIRD's and posterior shoulder tightness compared to control subjects
Torres and Gomes[16]	54 volunteers tennis players swimmers control group	No	-	Left side tested first Test position supine with elbow in 90° abduction	-	Dominant limbs had less IR than non-dominant limbs in all groups The IR deficit in tennis players was double the deficit found for swimmers
Ellenbecker et al.[134]	163 elite athletes 117 tennis players 46 baseball players	No	-	Test position supine with elbow in 90° abduction	-	Rotational patterning in unilaterally dominant overhead athletes is important for injury prevention, rehabilitation and improving performance

Key: - Not mentioned; SEM – standard error of the mean; ICC – intraclass correlation coefficient, r – correlation coefficient, BHJMI – Beighton and Horan Joint Mobility Index, HHD – hand held dynamometer, GIRD – glenohumeral rotation deficit.

2.8 SUMMARY OF THE LITERATURE

The popularity of participation in competitive swimming has increased in recent years[20]. Rigorous training regimes have raised concerns regarding the severity and incidence of injuries affecting competitive swimmers[30]. Many epidemiological studies investigating injuries in competitive swimmers have focussed on specific injury locations and types[8,26,29,30,41]. The most common injury locations include the shoulder, knee and spine[26,27]. Limited published information exists regarding the overall incidence and distribution of swimming injuries[29,30,38]. Furthermore, many studies investigating specific swimming injuries included purely adult or mixed adult-adolescent swimming cohorts.

There has been a surge of adolescent sport participation in the last 20 to 30 years[12,31,32,34,40,61]. Inherently, the number of adolescents partaking in competitive swimming has also increased. The importance of regular exercise during the adolescent growth phase has been extensively documented[12,34,55,56] and is known to improve the mineral content and density of bone[57]. Despite numerous health benefits, however, adolescents' rapid growth phase increases susceptibility to injury[33,51,68]. One of the reasons for young athletes' increased vulnerability is the immature musculoskeletal system; adolescents are more likely than adults to present with injuries to bone, cartilage, apophyses and growth plates[58]. The heightened physical susceptibility combined with the repetitive nature of swimming training, increases risk of injuries in adolescent swimmers[8,26,41,72]. Despite this, there is limited research on both specific injury locations and injury incidence in young, competitive swimmers[74]. To date, no study was found which prospectively investigated the overall injury incidence of adolescent swimmers over one season. Accordingly, the aim of this study is to determine injury incidence and potential risk factors for injury in adolescent swimmers over a 24-week period.

CHAPTER 3: THE EPIDEMIOLOGY OF INJURIES IN COMPETITIVE SWIMMING ADOLESCENTS ATTENDING A JOHANNESBURG SWIM SQUAD

3.1 INTRODUCTION

Swimming is a popular competitive and recreational sport performed worldwide by all generations. Swimming combines elements of both cardiovascular and strength training[26,27], and has many associated health benefits[8,27]. However, competitive swimmers may be at increased risk of injury, due to regular participation in demanding training regimes[26–28]. Adolescent swimmers may be at increased risk of injury due to physiological and biological vulnerability associated with growth and development[33–36]. However, there is a lack of evidence regarding the epidemiology of injuries in competitive adolescent swimmers.

Accordingly, the aim of this study was to determine the relationship between injury incidence and potential risk factors in adolescent swimmers over a 24-week period. The specific objectives of this study have been described in Section 1.2.2 (page 2).

3.2 METHODS

3.2.1 Research design and participants

This study had a descriptive, prospective and longitudinal design. Twenty three male and female adolescent swimmers were recruited for this study.

3.2.1.1 Inclusion criteria

Competitive male and female swimmers, aged 12 to 18 years, who were members of a Johannesburg-based swim squad were included in this study. Participants were only included if they intended to attend swimming training for the six-month study duration.

3.2.1.2 Exclusion criteria

Participants were excluded if they did not provide their own written informed assent (Appendix 5) or their parents/legal guardians' informed consent (Appendix 6) to participate in the study. Participants were excluded if they did not attend a minimum of the first four weeks of swimming training sessions, whilst completing the electronic version of the Injury report and training questionnaire.

3.2.2 Sample size determination

The main outcome measure of the study was injury incidence; therefore it was necessary to consider incidence rates whilst determining the sample size. Current literature reports that the incidence of swimming related injuries ranges between 3.5 and 6.5 injuries per 1 000 athletic exposures (AE's) or 1 000 hours of participation[26,29,30]. A one-proportion (Z-Chi-square) power calculation was performed in Statistica (StatSoft, Inc. 2004. STATISTICA, Data Analysis Software System, Version 11, www.statsoft.com). With statistical significance accepted as $p < 0.05$, a null proportion of 0.3 and a population proportion of 0.5, a sample size of 30, 40, and 50 participants would have provided 70%, 73% and 85% power respectively. Further, with statistical significance accepted as $p < 0.05$, a null proportion of 0.2 and a population proportion of 0.5, a sample size of 30, 40, and 50 participants would have provided 93%, 98% and 99% power respectively. Therefore, a minimum sample size of 30 participants was required to ensure 70% statistical power. Unfortunately, due to a shortage of volunteers from the club, the sample size for this study was only 23 participants.

3.2.3 Participant recruitment

The swim squad, based in Johannesburg, was a sample of convenience and selected as the primary recruitment site. Convenience consisted of an existing acquaintance between the study investigator and swim squad director. The squad was divided into three groups (juniors, seniors, elite swimmers), categorised according to age and swimming merit. Participants were recruited from all three groups. An email containing the information sheet (Appendix 6) was sent to all parents of squad members. An information session was held for swimmers to inform them of the study purpose and to recruit volunteers. The information sheets for participants (Appendix 5) and assent forms were handed out at the information session.

3.2.4 Measurement instruments

3.2.4.1 Informed assent and consent form

As all of the participants were minors, they needed to complete informed assent forms. Parents/legal guardians were requested to complete informed consent forms to give permission for their child to be approached to take part in this study. The informed assent and consent forms included a description of all study tests and procedures, information regarding the attainment of ethical approval, the testing benefits and potential risks, the study significance and the right to withdraw from the study at any time. Participants and parents/legal guardians were also assured that individual privacy and confidentiality of data would be strictly maintained.

3.2.4.2 Baseline questionnaire

The Baseline questionnaire (Appendix 7), completed once-off at baseline data collection, was adapted from a questionnaire used in a previous study by Walker et al[41]. Doctor Walker was contacted via email upon which she forwarded her original Prospective study questionnaire, along with permission to use it in the current study. She was initially informed of the scope of this study (investigation of general injury incidence in adolescent swimmers). This implied that the Prospective study questionnaire would require modification, since her original study assessed only shoulder injuries in adolescent to adult swimmers. No additional permission was needed to alter the original questionnaire. Please refer to Section 3.2.5.2 (page 63) for the validation process of this tool.

The Baseline questionnaire consisted of four subsections depicting demographic, competition, training and injury profiles over the previous 12 months. Much of this information was retrospective and gained prior to the study beginning, hence refers to historical training and competition characteristics. Historical training characteristics encompassed: age at which competitive swimming began, cumulative years of competitive swimming, dry-land training sessions per week, allocation of stroke percentage during training, dominant hand, preferred breathing side, regular inclusion of stretching during training, hand-paddle use per week and annual musculoskeletal training. Historical competition characteristics included the discipline swum at major competitions, the highest level of competition achieved and the stroke disciplines swum at competitions.

The injury profile, also historical in nature, was subdivided into three parts. Part one assessed injuries of the last year, comprising injury location, resultant activity modification, body side and preventative measures taken. Part two evaluated activity restriction of a specific injury over the last 12 months. Part three evaluated current pain and activity restriction on the day of baseline screening. Since the previous study investigated shoulder injuries only, the current study necessitated that amendments be made to the injury profile. These adjustments included representation of the entire body as a site for potential injury. Each participant completed the questionnaire whilst seated alongside a research assistant. The assistant read the questions out loud and provided clarification where necessary.

a) Validation of the Baseline questionnaire

The validation of the questionnaire is discussed in Section 3.2.5.2 (page 63).

3.2.4.3 Anthropometry measurements

The anthropometric measures of all participants were included in the Baseline questionnaire and were obtained by a research assistant. Height (cm) was measured using a stadiometer (Seca model, 708 Germany). Body mass (kg) was measured using a calibrated scale (Seca model, 708 Germany). The Body Mass Index (BMI) is a method used for measuring body composition and a recommended tool for obesity screening in youth[145,146]. Height and weight are used to calculate the BMI in the following formula[145,146]:

$$BMI = Weight\ (kg) / Height^2\ (m^2)$$

3.2.4.4 Measurement of glenohumeral internal rotation deficit and total arc of motion deficit

Glenohumeral rotation range of movement (ROM) was measured by two research assistants. Assistant one passively performed the movement whilst the assistant two measured the rotation ROM using a goniometer. The left side and internal rotation were measured first in all participants, irrespective of hand dominance. The measuring positions were adopted from various other studies and are described in Table 3.1[15,16].

Glenohumeral rotation ROM was used to calculate the following: glenohumeral internal rotation deficit, total arc of motion, total arc of motion deficit. Glenohumeral internal rotation deficit (GIRD) was calculated by subtracting the internal rotation value of the dominant from the non-dominant arm. The total arc of motion (TAM) was calculated as the sum of glenohumeral internal and external rotation on left and right sides respectively. Total arc of motion deficit (TAMD) was calculated as the difference in the total arc of motion between left and right sides.

Table 3.1: Measurement of glenohumeral rotation range of movement.

Glenohumeral test	**Starting position**	**End position**	**Goniometer position**	**Pictures of test**
Internal rotation (°)	Lie supine on plinth. 90° shoulder abduction, 90° elbow flexion, arm in body plane. Starting position 0° with forearm perpendicular to floor. Downward pressure applied to anterior shoulder to stabilize scapula.	Tester internally rotates arm only until posterior scapula rotation occurs.	Stationary arm: perpendicular to the table. Mobile arm: in alignment with forearm starting at olecranon and pointing at ulnar styloid process. Fulcrum: over olecranon process.	
External rotation (°)	Lie supine on plinth. 90° shoulder abduction, 90° elbow flexion, arm in body plane. Starting position 0° with forearm perpendicular to floor. Pressure applied to anterior shoulder to stabilize scapula.	Tester maximally externally rotates arm.	Stationary arm: perpendicular to the table. Mobile arm: in alignment with forearm starting at olecranon and pointing at ulnar styloid process. Fulcrum: over olecranon process.	

3.2.4.5 Measurement of hypermobility

The Beighton Score (BS) was used as a screening tool to measure joint mobility (Appendix 3). The standardised joint mobility protocol was used to determine the starting positions, test motions, anatomic landmarks and goniometer placements[109] and is depicted in Table 3.2. Passive, pain-free and bilateral range of movement was assessed in the first four test items. Items one and four were performed by participants themselves. Items two and three were performed by two research assistants; one assistant performed the movement whilst the other measured range of movement, thus ensuring accurate goniometer placement. Measurements were obtained using a finger goniometer (item one) and standard goniometer (item two and three). Item five was actively achieved actively by each participant. The scoring system was described in Section 2.7.4 (page 43).

Table 3.2: Measurement of the Beighton Score.

Motion tested (item)	Test position	Goniometer positioning and anatomic landmarks	Method	Positive score:	Pictures of test
Passive dorsiflexion fifth finger (°)	Sit on chair at the short side of plinth. Arm in 80° of abduction, elbow flexed 90°. Forearm pronated and resting on the table.	Stationary arm: parallel to fifth metacarpal. Mobile arm: parallel to fifth digit. Fulcrum: fifth metacarpophalangeal joint.	Lateral	≥90°	
Passive hyperextension of the elbow (°)	Lie supine on plinth. Shoulder in neutral in anatomic plane. Forearm supinated. Tester to stabilise humerus at one end and radius / ulna at the other end.	Stationary arm: parallel to humerus pointing to greater tuberosity. Mobile arm: parallel to radius pointing at radial styloid process. Fulcrum: lateral humeral epicondyle.	Lateral	≥10°	
Passive hyperextension of the knee (°)	Lie supine on plinth. Hip in neutral. Tester to stabilise femur whilst holding around malleoli with the other hand.	Stationary arm: parallel to femur pointing at greater trochanter. Mobile arm: parallel to fibula pointing at lateral malleolus. Fulcrum: Lateral femoral epicondyle.	Lateral	≥10°	

Table 3.2: Measurement of the Beighton Score continued.

Motion tested (item)	Test position	Goniometer positioning and anatomic landmarks	Method	Positive score:	Pictures of test
Passive opposition of thumb to flexor side of forearm	Shoulder flexed to 90° and elbow extended. Forearm pronated. Opposition pressure applied to the interphalangeal joint of thumb.	Not applicable	Not applicable	Whole thumb must touch flexor side of forearm.	
Trunk flexion	Standing with feet hip width apart and knees straight. Perform forward flexion of trunk and hips.	Not applicable	Not applicable	Hand palms rest easily on the floor.	

3.2.4.6 Muscle strength measurements

Glenohumeral and knee muscle strength was measured using a Lafayette manual muscle tester, which is also known as a hand held dynamometer (HHD). The starting positions for these measurements were adopted from previous studies[42,100,128,136,137] and are shown in Table 3.3. All strength tests were administered by the study investigator throughout screening. An assistant recorded strength values to one decimal point. The following movements were used to assess shoulder strength: elevation, hand behind back lift-off, horizontal abduction, external rotation and internal rotation. Knee flexion and extension strength were also assessed.

Each participant received a thorough explanation and careful demonstration of the required movement. The HHD was placed against the limb being tested and a familiarisation trial run at submaximal effort was conducted. Refer to Section 2.7.5 (page 45) for testing procedures.

Table 3.3: Measurement of glenohumeral and knee muscle strength

Motion tested	Starting position	HHD position
Elevation[128]	Sit on chair with both feet on the floor 90° shoulder flexion and 30° horizontal abduction (palm down)	HHD placed centrally onto dorsal aspect of distal forearm (parallel to ground) Caudad force is exerted through HHD by tester
Hand behind back lift-off[128]	Sit on chair with both feet on the floor Upper limb placed behind back in the midline (no contact of hand with back)	HHD placed centrally onto palmar aspect of distal forearm (perpendicular to forearm) Anterior force is exerted through HHD by tester
Horizontal abduction[42,100]	Lie prone on plinth Upper limb placed in 90° abduction, full elbow extension and wrist in neutral (palm down)	HHD placed centrally onto dorsal surface of distal forearm (parallel to ground) Downward force exerted through HHD by tester
External rotation[42,100]	Lie prone on plinth 90° shoulder abduction, 0° rotation and elbow flexed to 90° Humerus stabilised distally against plinth	HHD placed centrally onto dorsal surface of distal forearm (perpendicular to ground) Caudad force is exerted through HHD by tester
Internal rotation[42,100]	Lie prone on plinth 90° shoulder abduction, 0° rotation and elbow flexed to 90° Humerus stabilised distally against plinth	HHD placed centrally onto palmar surface of distal (perpendicular to ground) Cephalad force is exerted through HHD by tester

Key: HHD: hand held dynamometer

Table 3.3: ***Measurement of glenohumeral and knee muscle strength continued***

Motion tested	Starting position	HHD position	Pictures of test
Knee Flexion [136,137]	Sit at edge of plinth with feet hanging free. Hips and knees at 90° flexion.	HHD placed on posterior aspect of calcaneus (perpendicular to leg). Posterior force through HHD by participant while tester stabilises.	
Knee extension [136,137]	Sit at edge of plinth with feet hanging free. Hips and knees at 90° flexion.	HHD placed onto anterior aspect of distal tibia, five cm proximal to medial malleolus (perpendicular to leg). Anterior force through HHD by participant while tester stabilises.	

Key: HHD: hand held dynamometer

3.2.4.7 Online Injury report and training questionnaire

An injury report and training questionnaire was obtained from the same author[41] as the Baseline Questionnaire. Hence, the permission gained to use the original report form was previously described in Section 3.2.4.2 (page 53). The original questionnaire necessitated modification, the validation of which is discussed in Section 3.2.5.2 (63). Following validation, the modified Injury report and training questionnaire was converted to an electronic version which was uploaded onto ©FluidSurvey (Appendix 2). The questionnaire constituted two main sections; injury reporting and training exposure.

a) Injury section

Simple questions were asked to gain insight and an overview of injury incidence (injury % per athletic exposure). Injuries reported during the study period did not require assessment or treatment by a medical professional. Adolescents were asked to report an injury if it caused even minimal discomfort or pain, but did not always necessitate modification or cessation of swimming training. Participants were asked not to include very minor injuries like lacerations and bruises. The injury section encompassed: injury type, location, body side, index or recurrent injury, severity, aggravating factors and treatment received. Injury severity was ranked on a pain scale of zero to ten, at rest and while swimming. Zero meant *'no pain'* and ten points meant the *'worst pain ever'*. This was followed by recording the amount of training either missed or changed as a result of injury. For every injury, participants were requested to self-report the mechanism of injury such as swimming training, dry-land training and other sport participation (Appendix 2).

b) Training exposure section

The training exposure section included a log of the days and sessions per week for 24 weeks (six months). The average duration per session and total training duration per week were recorded in hours. The average distance covered per session was recorded in kilometres. The number of competitions and dry-land training sessions were documented. Participants were requested to view competition participation as one overall competitive occurrence per day. This meant one competition could constitute numerous 'swimming events', entailing varying strokes and distances, swum in succession. Documenting dry-land training included the recording of the average session duration and exercises completed during this time. Participation in other sports activities, such as school sports, was incorporated into this section. 'Participation in other sports' was measured in athletic exposures (AE), where one practice session equalled one AE (Section 2.7.2.2, page 41). The distinction between dry-land training and other sport participation was made to determine whether one of these variables would have greater risk in this study.

The intensity (expressed as rate of perceived exertion) of weekly training was documented using the modified Borg Scale[116] (Appendix 8). Participants responded to the question: *'please choose a number that best describes how difficult your swim training sessions were this past week on average?'* The point scale, ranging from zero to ten allocated a numeric value to the level of difficulty: zero equalled 'rest', one meant 'really easy', two 'easy', three 'moderate', four 'sort of hard', five 'hard', seven 'really hard', nine 'really, really hard' and ten meant 'maximal, just like my hardest race'.

3.2.5 Reliability

3.2.5.1 Feasibility study

A feasibility study was conducted to assess the intra-rater reliability for the hand-held dynamometer. A sample of convenience, including three participants, was used. The inclusion criteria for the reliability study were not matched to the main study inclusion criteria. For the reliability study, participants ranged from 30 to 58 years old, were of mild to moderate fitness and were not swimmers. The strength measurements were performed on two non-consecutive days. One day recovery was given between the two days to allow participants to recover from potential delayed onset of muscle soreness. As would be the case in the study, a trial-run followed by three measurements of each test motion were completed to obtain an average. Data from participants in the reliability study were not included in the primary research study.

3.2.5.2 Validation of questionnaires

The Baseline questionnaire and Injury report and training questionnaire both underwent a process of expert validation as they required alteration from original versions. A panel of four physiotherapists, with interests in both swimming and youth sports were asked to review the modified questionnaires. The panel of experts was required to evaluate whether the questionnaires were straightforward, simple and aimed at appropriate levels of understanding for adolescents. Hence, content and construct validity were simultaneously addressed. This modification further aimed to increase compliance from participants over a six-month period. Feedback and recommendations were given by the panel and further amendments made until final versions of both forms were accepted by all.

3.2.5.3 Training of research assistants

Four physiotherapy students were recruited from the University of the Witwatersrand to assist with baseline data collection. These research assistants received training on the administration of measurement instruments one hour prior to commencing the first assessment. Assistants one and two were shown how to measure glenohumeral rotation range of motion and administer the Beighton Score. Assistants three and four were taught how to assist participants with completion of Baseline questionnaires and record anthropometry measurements. Training included a verbal description of the purpose of each measurement instrument followed by demonstrations of the physical tests to be performed. Assistants also received laminated copies of all tests with clear instructions, descriptions and pictures. As physiotherapy students they were familiar with the measurement of range of movement, however to ensure accuracy of goniometer placement, they were shown how to mark relevant anatomical landmarks with a pen. The assistants were given the opportunity to ask questions and practice the tools on each other. Muscle strength measurements were performed exclusively by the study investigator who had completed the reliability study, hence did not require training of research assistants.

3.2.6 Study procedure

3.2.6.1 Preparation

The director of a Johannesburg-based swim squad was approached with the study purpose and procedure (Appendix 9) upon which he consented to the squads' participation in the study. The 24-week study period was chosen, from the months of October to April, to coincide with the approximate mid-season of the swimming calendar. Anecdotal evidence suggests that competition volumes and training loads were highest during this time.

After obtaining ethics approval, parents of all club members were emailed the study information sheet, consent form and details of an imminent information session for the swimmers. The information session took place one day immediately after training and all present were given their own information sheets and assent forms. Since club members of all ages were present, the specific age-group required (12 to 18 years) was particularly emphasized. Members unable to attend the information session were informed of the study scope by their parents. Parents were then individually contacted to further answer questions and address concerns. Eighteen parents consented to their child's participation once these swimmers had expressed a willingness to volunteer. Five of the 18 parents consented to both siblings participation, totalling 23 participants.

Research assistants were recruited and provided with access cards to the Virgin Active premises (Appendix 10). It was arranged with the club manager that a private room be provided to facilitate baseline data collection. The room size and number of research assistants allowed for two participants to be assessed simultaneously. A time-table, with one-hour-long slots, was drawn up for the data collection period. Parents received the time-table via email and allocated their child to a time-slot of preferred suitability on a first-come-first-serve basis. Confirmation emails and mobile text-message reminders of the assessment date and time were sent to parents once the time-table was finalized.

3.2.6.2 Baseline screening tests

Participants brought their parent's signed consent forms with them when appearing for baseline data collection. They signed their own assent forms on site after a thorough explanation from and under the supervision of a research assistant. Participants also provided their email addresses and cell phones numbers to enable communication throughout the study period.

The following were measured during baseline screening: glenohumeral internal rotation deficit (GIRD), total arc of motion deficit (TAMD), Beighton score, shoulder and knee muscle strength.
No participants reported any pain during baseline testing. Some participants reported only minor muscular discomfort after the third repeat of the strength tests from the effort of contractions at maximum capacity.

3.2.6.3 Online Injury report and training questionnaire

At baseline data collection participants were briefed on how to access the electronic survey via the ©Survey Monkey link. The week following the initial data collection, a trial-run of the online Injury report and training report questionnaire was sent to participants. The trial-run allowed swimmers to familiarise themselves with the tool and enabled the study investigator to correct any errors which had arisen.

The ©Survey Monkey link with the Injury report and training log lasted a total of 24 weeks, from the beginning of November 2014 until the end of April 2015. The web-based logs were completed weekly (i.e. retrospectively) for training from Monday to Sunday; the electronic link was sent via email on a Sunday night. The email contained the following details: participant name, week number of the survey and the date pertinent to each particular week. Participants were asked to complete the questionnaire from the last day of training per week until no later than day seven.

Participants who had not returned completed questionnaires by Friday each week received reminders via WhatsApp or email. If surveys were not completed for three weeks, the parents of participants were contacted. It was taken into account that on occasion participants did not have access to the internet. In such circumstances, participants were asked to keep a manual log of injury and training information. This information was then uploaded to the electronic system at a later stage.

At week 17 of the log, the survey engine necessitated change due to unforeseen circumstances. It was changed from ©Fluid Survey to ©Survey Monkey. This abrupt change resulted in a delay of five days in sending out the new survey link. As a result, compliance was lost from three participants, who subsequently requested to exit the study. All three participants stated the following reason: the new survey engine was not convenient as they could no longer access the link from home computers or cellular telephones due to increased security settings.

3.2.7 Statistical analysis

Statistical analyses were performed using Statistica software (StatSoft, Inc. 2004) STATISTICA (Data analysis software system, version 11, www.statsoft.com). The Shapiro-Wilkes test was used to assess normality. An independent t-test was used to determine differences in demographic characteristics, historical training and competition characteristics, baseline screening tests and cumulative training characteristics between injured and uninjured groups. Differences in ordinal data between injured and uninjured groups were evaluated using frequency tables and Chi-squared tests. Statistical significance for the two main effects of group (injured and uninjured) and time, and the interaction (group x time) of variables (average session duration, average session distance, weekly swim sessions, weekly training duration, weekly training distance, weekly intensity of training) were assessed using a two-way analysis of variance (ANOVA) with repeated measures. An unequal HSD post-hoc test was performed where necessary. Odds ratios were performed to determine any factors that might be associated with an increased likelihood for injury. Odds ratios were determined using DAG Stat[147]. Effect sizes were assessed for descriptive characteristics and musculoskeletal screening tests in injured and uninjured groups. The effect size (d) was calculated using a spreadsheet downloaded from www.work-learning.com/effect_sizes.htm. The following criteria were used: Cohen's d: d = 0.2-0.49 (small effect size); d = 0.5-0.79 (medium effect size); d = 0.8 or above (large effect size). All numeric data are presented as the mean ± standard deviation (SD). Categorical data are presented as number of responses and percentages. Statistical significance was accepted as $p < 0.05$.

Table 3.4: Binary coding for potential factors associated with injury risk in participants (n = 23)

Variable	Binary code 0	Binary code 1
Descriptive characteristics		
Age (y)	≥ 14	< 13.9
Mass (kg)	> 55	≤ 55
BMI ($kg.m^{-2}$)	≥ 20	< 20
Previous injury history	No	Yes
Gender	Male	Female
Dominant hand	Left	Right
Screening characteristics		
Total arc of motion deficit (°)	≤ 5	> 5
GH internal rotation deficit (°)	< 10	≥ 10
Beighton score (n)	< 5	≥ 5
GH elevation (J)	≥ 70	< 70
GH lift-off (J)	≥ 100	< 100
GH horizontal abduction (J)	≥ 50	< 50
GH external rotation (J)	≥ 90	< 90
GH internal rotation (J)	≥ 120	< 120
Knee flexion (J)	≥ 170	< 170
Knee extension (J)	≥ 240	< 240
Training and competition characteristics		
Other sport participation	No	Yes
Freestyle swum during training (%)	< 40	≥ 40
Breaststroke swum during training (%)	≥ 20	< 20
Hand paddle use / week (n)	0	≥ 1
Cumulative training distance (km)	≥ 600	< 600
Cumulative training duration (h)	≥ 180	< 180
Cumulative time spent swimming competitively (y)	≥ 6	< 6

3.2.8 Ethical considerations

The proposal was submitted to the University of Cape Town, Faculty of Health Sciences Human Research Ethics Committee. Ethics approval was obtained prior to study commencement (HREC REF: 768/2014) (Appendix 11). The study was carried out in accordance with the principles of the Declaration of Helsinki, Fortaleza, Brazil, 2013. Parents/legal guardians and participants were informed about the study purpose, the baseline testing procedures and any potential risks associated with study participation.

Parents/legal guardians and adolescents were required to provide informed consent and assent respectively, given that all participants were minors. The right to withdraw at any stage was explained to all parties. Guardians and swimmers were reminded that the purpose of study was not to provide physiotherapeutic or other treatment for injuries sustained during the course of the study.

Only the study investigator and research assistants were privy to participant information during baseline data collection to ensure confidentiality. Information collected from Baseline questionnaires and physical testing was placed into a separate folder by the study investigator. The electronic survey accounts were password protected. Only the study investigator and University of Cape Town supervisor had access to the main database for processing. Confidentiality was further ensured as no names will be mentioned in the study write-up or any ensuing publications.

3.2.8.1 Risks to participants

The study participants were all competitive swimmers; therefore the very nature of their standard swim training regime placed them at risk of sustaining musculoskeletal injuries. The physical nature of some of the screening tests placed the adolescents at risk of injury. To reduce this risk, screening was performed once-off, ensuring no further risk from repeated physical assessments. Participants were thoroughly briefed about the purpose of all tests and received clear instructions, pictures and demonstrations where necessary. Adolescents were encouraged to ask questions if they did not understand the test procedure. The assessments were conducted in a safe, private room. No participant complained of pain during any of the baseline tests.

Prior to administration of each muscle strength test at baseline, participants performed a trial run of the required test with a submaximal muscle contraction (i.e. an estimated 50 % contraction). The trial run aimed to increase familiarisation of each test, thereby decreasing risk of injury from incorrect or compensatory actions. Participants may still have experienced delayed onset of muscle soreness the following day from performing the actual strength tests; three repeats at maximal contraction were completed.

3.2.8.2 Benefits to participants

After study completion participants received feedback on the outcome of screening tests including: muscle strength of glenohumeral and knee joints and muscle balance left versus right; glenohumeral internal rotation, glenohumeral external rotation and total arc of motion measurements; and generalised ligament integrity. The results of baseline tests were analysed after study completion. Any participants presenting with strength discrepancies between sides or agonist / antagonist muscles were advised that completing a specific strengthening programme might be of benefit. It was recommended that participants consult with a physiotherapist or biokineticist* of their choice for an in-depth musculoskeletal assessment with provision of a rehabilitation programme. Participants were also given a summary of the results of the study.

* Biokineticist is concerned with preventative health care and final phase rehabilitation by means of scientifically-based physical activity programmes[176].

3.3 RESULTS

3.3.1 Participants

Twenty three participants were recruited for the study. Data from all 23 participants were included for analysis. According to exclusion criteria, participants were only excluded if they did not complete the first four weeks of the study period. Therefore, at study completion, the uninjured group comprised nine participants; and 14 participants formed the injured group. The group allocation only occurred on study completion.

However, five participants dropped out at different stages of the study period, due to personal and logistical reasons. One participant dropped out at week six due to study commitments, and another participant dropped out at week 11 due to personal reasons. Between weeks 16 and 17 of the study period, there was an unforeseen change in the online survey tool, which resulted in a slight delay in the weekly survey, and participants were required to use a new link to access the survey. Unfortunately, three participants dropped out at week 17. Therefore, 18 of the 23 participants who were enrolled completed the full study period. This is a retention rate of 78%.

In the presentation of the study results, all descriptive and baseline data reflect the full sample of 23 participants. However, for the weekly training and injury results, analyses were conducted with the different sample sizes at respective weeks. The weekly sample sizes were as follows: weeks 1 - 5, n = 23 (injured group n = 7, uninjured group n = 16); weeks 6 - 10, n = 22 (injured group n = 8, uninjured group n = 14); weeks 11 - 16, n = 21 (injured group n = 10, uninjured group n = 11); and weeks 17 - 24, n = 18 (injured group n = 12, uninjured group n = 6). To avoid unnecessary repetition, group numbers have not been included in the legend text of tables and figures for weekly training and injury results.

3.3.2 Descriptive characteristics

3.3.2.1 Demographic characteristics

The demographic characteristics of participants are shown in Table 3.5. There were no significant differences between the injured and uninjured groups for these variables.

Table 3.5: Descriptive characteristics of participants in the uninjured (n = 9) and injured (n = 14) groups. Data are expressed as mean ± standard deviation (SD).

Variable	Uninjured (n = 9)	Injured (n = 14)	p	t	95% CIs
Age (years)	14.2 ± 1.6	13.9 ± 1.3	0.63	0.48	-0.97 – 1.56
Stature (m)	1.7 ± 0.1	1.7 ± 0.1	0.52	0.65	-0.05 – 0.10
Mass (kg)	58.9 ± 8.3	54.6 ± 9.2	0.27	1.14	-3.58 – 12.22
Body mass index (kg.m^{-2})	20.3 ± 1.6	19.3 ± 1.6	0.15	1.51	-0.38 – 2.39

3.3.2.2 Historical training and competition characteristics

The nominal historical training data of the uninjured and injured groups are shown in Table 3.6. There was a significant difference between groups in the percentage of breaststroke swum during training, with the uninjured group completing a significantly higher percentage of breaststroke training ($p = 0.011$). A large effect size ($d = 1.14$) was also observed for this variable. Ordinal historical training characteristics and ordinal historical competition characteristics are represented in Tables 3.7 and 3.8 respectively. There were no significant differences between groups for any of the ordinal training or competition characteristics.

Table 3.6: Nominal historical training characteristics of participants in the uninjured (n = 9) and injured (n = 14) groups. Data are expressed as mean ± SD.

Variable	*Uninjured* (n = 9)	*Injured* (n = 14)	*p*	*t*	*95% CIs*	*Effect size (d)* †
Age at which competitive swimming began (y)	7.6 ± 3.1	7.7 ± 3.4	0.91	-0.11	-3.11 – 2.79	-0.03
Cumulative time spent swimming competitively (y)	6.6 ± 3.7	5.9 ± 2.7	0.61	0.53	-2.07 – 3.47	0.22
Land training sessions / week	2.2 ± 1.1	2.2 ± 1.1	0.99	0.02	-0.98 – 1.00	0
Freestyle stroke swum during training (%)	38.3 ± 22.6	57.1 ± 21.1	0.06	-2.03	-38.09 – 0.47	-0.84
Butterfly stroke swum during training (%)	11.3 ± 4.6	8.6 ± 6.2	0.28	1.12	-2.33 – 7.71	0.46
Backstroke swum during training (%)	10.3 ± 10.3	19.1 ± 15.7	0.16	-1.47	-21.07 – 3.59	-0.61
Breaststroke swum during training (%)	40.0 ± 27.8	15.1 ± 15.2	0.01*	2.78	6.27 – 43.45	1.14

*$p < 0.05$
†Cohen's d: d = 0.2 (small effect size), d = 0.5 (medium effect size), d = 0.8 (large effect size)

Table 3.7: Ordinal historical training characteristics of participants in the uninjured (n = 9) and injured (n = 14) groups. Data are expressed as numbers and percentage.

Variable		**Uninjured (n = 9)**	**Injured (n = 14)**	**χ^2**	
		n (%)		**Pearson**	**p**
Gender	Male	3 (13)	5 (22)	0.01	0.91
	Female	6 (39)	9 (61)		
Dominant hand	Left	1 (4)	2 (9)	0.05	0.83
	Right	8 (35)	12 (52)		
Preferred breathing side	Left	1 (5)	4 (18)	2.12	0.35
	Right	1 (5)	4 (18)		
	Both	6 (27)	6 27)		
Regular inclusion of stretching for swimming training	Yes	2 (9)	5 (22)	0.47	0.49
	No	7 (30)	9 (39)		
Hand-paddle use / week (n)	None	1 (4)	1 (4)	0.24	0.89
	1 – 2	7 (30)	12 (52)		
	3 - 4	1 (4)	1 (4)		
Annual musculoskeletal screening (n)	0	8 (35)	10 (43)	1.19	0.55
	1	1 (4)	3 (13)		
	2	0 (0)	1 (4)		

Table 3.8: Ordinal historical competition characteristics of participants in the uninjured (n = 9) and injured (n = 14) groups. Data are expressed as numbers and percentages.

Variable		Uninjured (n = 9)	Injured (n = 14)	χ^2	
		n (%)		Pearson	p
Distance swum at major competitions (m)	Sprint	1 (4)	3 (13)	3.23	0.66
	Middle	1 (4)	2 (9)		
	Long	0 (0)	1 (4)		
	Sprint / middle	5 (22)	3 (13)		
	Sprint / middle / long	1 (4)	2 (9)		
	Middle / long	1 (4)	3 (13)		
Highest level of competition achieved	International	3 (13)	3 (13)	4.39	0.22
	National	2 (9)	8 (35)		
	Provincial	4 (17)	2 (9)		
	Regional	0 (0)	1 (4)		

Key: Sprint distance – 50 m/100 m, middle distance – 200 m/400 m, long distance – 800 m/1500 m, free - freestyle, back - backstroke, breast - breaststroke, fly – butterfly, IM - individual medley.

Table 3.8: Ordinal historical competition characteristics of participants in the uninjured (n = 9) and injured (n = 14) groups. Data are expressed as numbers and percentages continued.

Variable		**Uninjured (n = 9)**	**Injured (n = 14)**	**χ^2**	
		n (%)		**Pearson**	**p**
Stroke disciplines swum at competitions	Free / IM / Breast	1(4)	0 (0)	13.90	0.24
	Free / Back / IM	0 (0)	2 (9)		
	Free / IM / Breast / Fly	2 (9)	1 (4)		
	Free / Back	0 (0)	2 (9)		
	Free / Back / IM / Fly	2 (9)	0 (0)		
	Free / Back / IM / Breast / Fly	3 (13)	3 (13)		
	Free / Fly	0 (0)	2 (9)		
	Free / Back / IM / Breast	0 (0)	1 (4)		
	Back / IM / Fly	1 (4)	0 (0)		
	Free / Breast / Fly	0 (0)	1 (4)		
	Breast	0 (0)	1 (4)		
	Free / IM / Fly	0 (0)	1 (4)		

Key: Sprint distance – 50 m/100 m, middle distance – 200 m/400 m, long distance – 800 m/1500 m, free - freestyle, back - backstroke, breast - breaststroke, fly – butterfly, IM - individual medley.

3.3.3 Baseline screening tests

Glenohumeral range of movement (ROM) and Beighton Score variables of participants in the uninjured and injured groups are shown in Table 3.9. There were no significant differences between groups in glenohumeral ROM and Beighton Score variables assessed in this study.

Table 3.9: Glenohumeral range of movement (ROM) and Beighton Score total of participants in the uninjured (n = 9) and injured (n = 14) groups. Data are expressed as mean ± SD.

Glenohumeral range of movement	Body side	Uninjured (n = 9)	Injured (n = 14)	t	p	95% CIs	Effect size (d)
Glenohumeral internal rotation (°)	L	75.6 ± 9.2	78.6 ± 10.9	-0.68	0.50	-12.18 – 6.15	-0.28
	R	72.2 ± 9.1	78.1 ± 10.7	-1.36	0.19	-14.82 – 3.12	-0.56
Glenohumeral external rotation (°)	L	110.9 ± 12.5	107.1 ± 12.4	0.71	0.49	-7.28 – 14.77	0.29
	R	109 ± 11.4	110.6 ± 15.3	-0.26	0.80	-13.96 – 10.82	-0.11
Total arc of motion (°)	L	186.4 ± 15.4	185.7 ± 18.4	0.10	0.92	-14.67 – 16.13	0.04
	R	181.2 ± 16.8	188.6 ± 17.5	-1.01	0.33	-22.74 – 7.90	-0.41
Total arc of motion deficit (°)		7.9 ± 8.9	8.9 ± 6.2	-0.33	-0.33	0.74	-0.13
Glenohumeral internal rotation deficit (°)		5.8 ± 5.2	10.1 ± 8.7	-1.33	-1.33	0.20	-0.55
Beighton Score total		3.2 ± 1.7	3.1 ± 2.1	0.18	0.86	-1.57 – 1.87	0.05

Key: L – left, R – right.

Muscle strength of selected muscle groups of the glenohumeral and knee joints are shown in Table 3.11. There were significant differences between groups, with large effect sizes, in the glenohumeral lift-off test on the left (p = 0.015; d = 1.09) and right sides (p = 0.018; d = 1.05) respectively. There was no significant difference between groups for any other muscle strength measures.

Table 3.10: Glenohumeral and knee strength measurements of participants in the uninjured (n = 9) and injured (n = 14) groups. Data are expressed as mean ± SD.

Strength tests	**Side**	**Uninjured (n = 9)**	**Injured (n = 14)**	**t**	**p**	**95 CIs**	**Effect size (d)**
Glenohumeral elevation (J)	L	78.6 ± 23.3	60.1 ± 20	2.03	0.05	-0.38 – 37.50	0.84
	R	78.8 ± 27.1	61.2 ± 20.1	1.79	0.09	-2.85 – 38.04	0.73
Glenohumeral lift-off (J)	L	113.3 ± 35.3	82.7 ± 20.1	2.66	0.02*	6.67 – 54.44	1.09
	R	116.9 ± 33.8	83.9 ± 27.8	2.56	0.02*	6.21 – 59.92	1.05
Glenohumeral horizontal abduction (J)	L	55.1 ± 12.1	49.7 ± 17.6	0.81	0.43	-8.57 – 19.42	0.33
	R	58.6 ± 17	49.4 ± 19.3	1.18	0.25	-7.11 – 25.70	0.48
Glenohumeral external rotation (J)	L	91 ± 27.2	80.3 ± 24.7	0.97	0.34	-12.17 – 33.52	0.40
	R	102.8 ± 28.8	84 ± 17.2	1.97	0.06	-1.03 – 38.73	0.81
Glenohumeral internal rotation (J)	L	129.5 ± 47.8	107.4 ± 42.4	1.17	0.26	-17.38 – 61.74	0.48
	R	129.8 ± 42.2	119 ± 40.7	0.61	0.55	-25.95 – 47.44	0.25
Knee Flexion (J)	L	198.8 ± 53.5	160.2 ± 55.6	1.65	0.11	-10.10 – 87.30	0.68
	R	190 ± 38	164.7 ± 53.7	1.23	0.23	-17.57 – 68.30	0.51
Knee Extension (J)	L	259.5 ± 63.4	210.2 ± 75.8	1.62	0.12	-14.09 – 112.62	0.67
	R	259.1 ± 64.8	219.9 ± 78.5	1.25	0.23	-26.23 – 104.58	0.51

*$p < 0.05$

3.3.4 Training characteristics

3.3.4.1 Cumulative training distance and duration

The cumulative swimming training distance and duration over the 24-week study period of participants in the injured and uninjured groups are shown in Table 3.11. There were no significant differences in cumulative training characteristics between groups. Wide confidence intervals (CIs) can be seen in both cumulative training distance and total training durations.

Table 3.11: Summary of cumulative training characteristics of participants in the uninjured and injured groups. Data are expressed as mean ± SD.

Variable	Uninjured (n = 9)	Injured (n = 14)	t	p	95 CIs	Effect size (d)
Cumulative training distance (km)	584.3 ± 259.8	684.9 ± 236.4	-0.96	0.35	-318.82 – 117.63	-0.39
Cumulative training duration (h)	176.2 ± 74.3	191.3 ± 66.3	-0.51	0.62	-76.76 – 46.64	-0.21

3.3.4.2 Individual swim sessions

An individual swim session refers to one participant completing one pool practice session. Participants recorded their average session duration and average session distance each week of the study period. The average values of all participants for individual session duration and distance will be reviewed in this section.

a) Average session duration

The average swim session duration of participants in the uninjured and injured groups over the 24-week study period is shown in Figure 3.1. There were no significant differences in average swim session duration between groups ($F_{(23, 92)}$ = 1.8460; p = 0.02). However, there was a significant main effect of time for the average swim session duration (p = 0.02). There were no significant differences on further post hoc analysis.

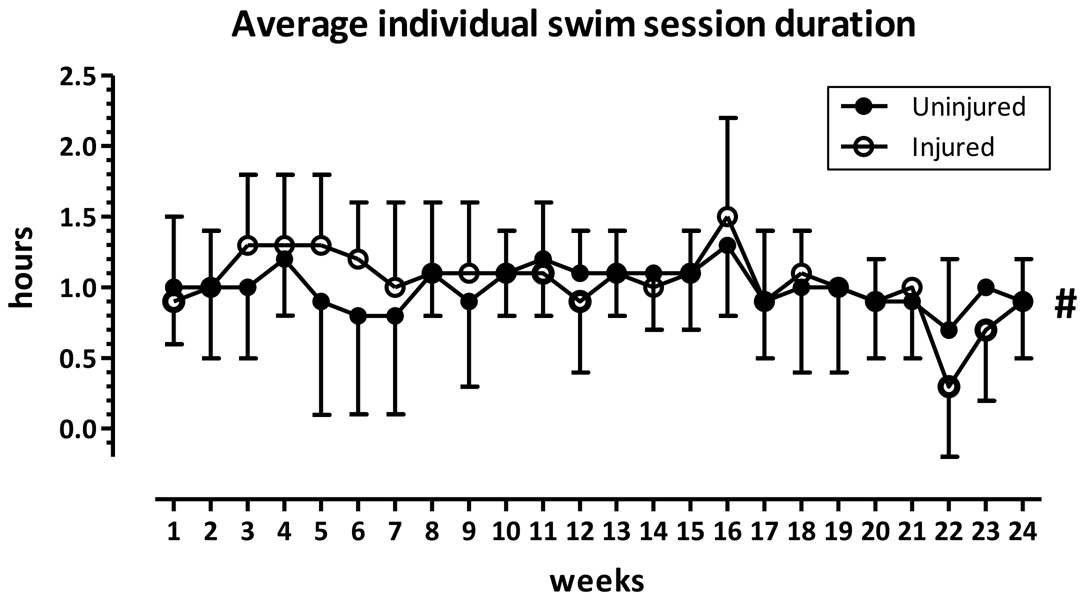

Figure 3.1: Average individual swim session duration (h) of participants in the uninjured and injured groups over the 24-week study period. Data are expressed as mean ± SD.

Significant differences:

main effect of time (p = 0.02)

b) Average session distance

The average individual swim session distance of participants in the uninjured and injured groups over the 24-week study period is shown in Figure 3.2. There was significant interaction between groups over time for average individual session distance ($F_{(23, 92)} = 1.7097$; $p = 0.04$). Although there were no significant differences on further post hoc analysis, there was a tendency for individual swim session distances to be lower in the uninjured group for most of the study period. However, there was a tendency for individual swim session distances to be lower in the injured group towards the end of the study period, particularly from week 22 to week 24.

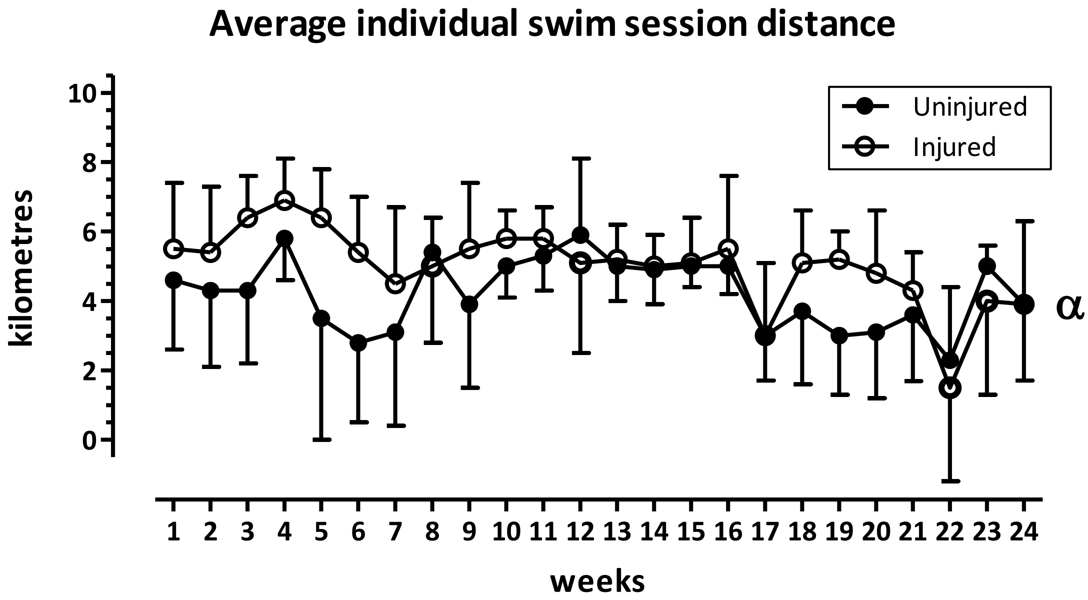

Figure 3.2: Average individual swim session distance (km) of participants in the uninjured and injured groups for the 24-week study period. Data are expressed as mean ± SD.

Significant differences:

α interaction of group x time (p = 0.04)

3.3.4.3 Weekly swim sessions

Weekly swim sessions is the cumulative total of practice sessions completed by one participant in one week. The average individual session duration and distance per participant was multiplied by their total number of weekly sessions. Thus, values for weekly training durations and distances were obtained. The average values of all participants for weekly swimming duration, distance and intensity for the 24-week study period will be reviewed in this section.

a) Number of weekly swim sessions

The number of weekly swim sessions of participants in the uninjured and injured groups over the 24-week study period is shown in Figure 3.3. There was a significant main effect of time for the number of sessions per week, with an overall reduction in the number of weekly swim sessions over the 24-week study period ($F_{(23,\ 92)} = 3.1685$; $p = 0.00005$). Post-hoc analysis showed that participants completed a significantly higher number of training sessions in week two compared to week 22 (p = 0.010); week four compared to weeks six (p = 0.002), 22 (p = 0.0003), 23 (p = 0.014) and 24 (p = 0.028); and week five compared to weeks six (p = 0.007), 22 (p = 0.001) and 23 (p = 0.039) respectively.

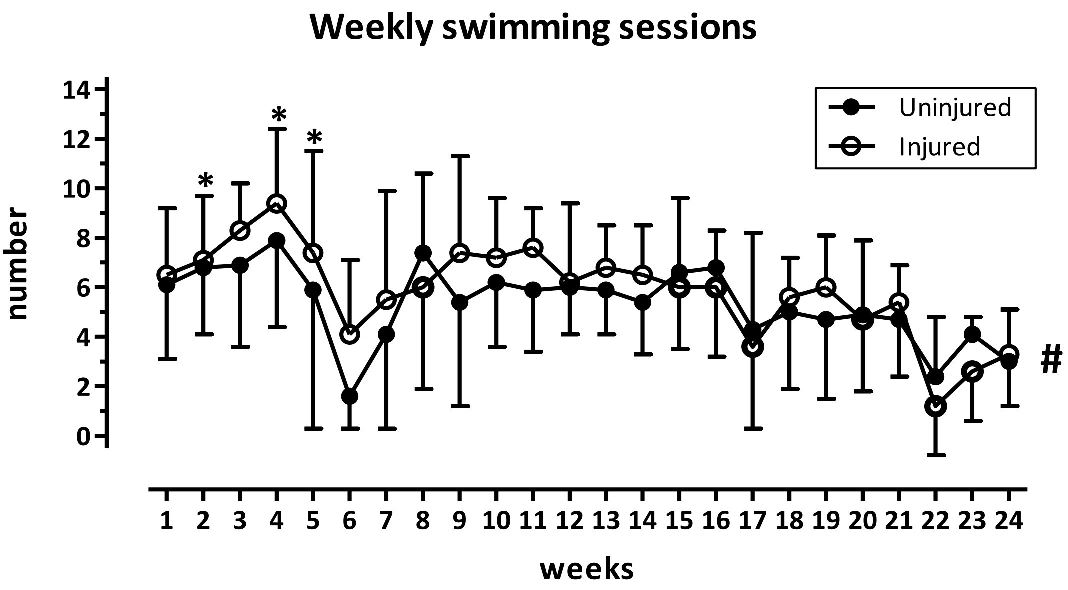

Figure 3.3: Weekly swim sessions (n) of participants in the uninjured and injured groups for the 24-week study period. Data are expressed as mean ± SD.

Significant differences:

main effect of time (p = 0.00005)

* week 2 vs. 22 (p = 0.010)

* week 4 vs. 6 (p = 0.002), 22 (p = 0.0003), 23 (p = 0.014) and 24 (p = 0.028)

* week 5 vs. 6 (p = 0.007), 22 (p = 0.001) and 23 (p = 0.039)

b) Weekly training duration

The weekly training duration of participants in the uninjured and injured groups over the 24-week study period is shown in Figure 3.4. There was a significant main effect of time for the duration of training per week ($F_{(23, 92)} = 1.8460$; $p = 0.021$). Post hoc analysis showed that participants completed significantly higher weekly training durations at week two compared to week 22 (p = 0.012); week four compared to weeks six (p = 0.001), 22 (p = 0.0003) and 23 (p = 0.004); week five compared to weeks six (p = 0.001), 22 (p = 0.0003) and 23 (p = 0.0003); week 11 compared to week 22 (p = 0.026); and week 12 compared to week 22 (p = 0.037).

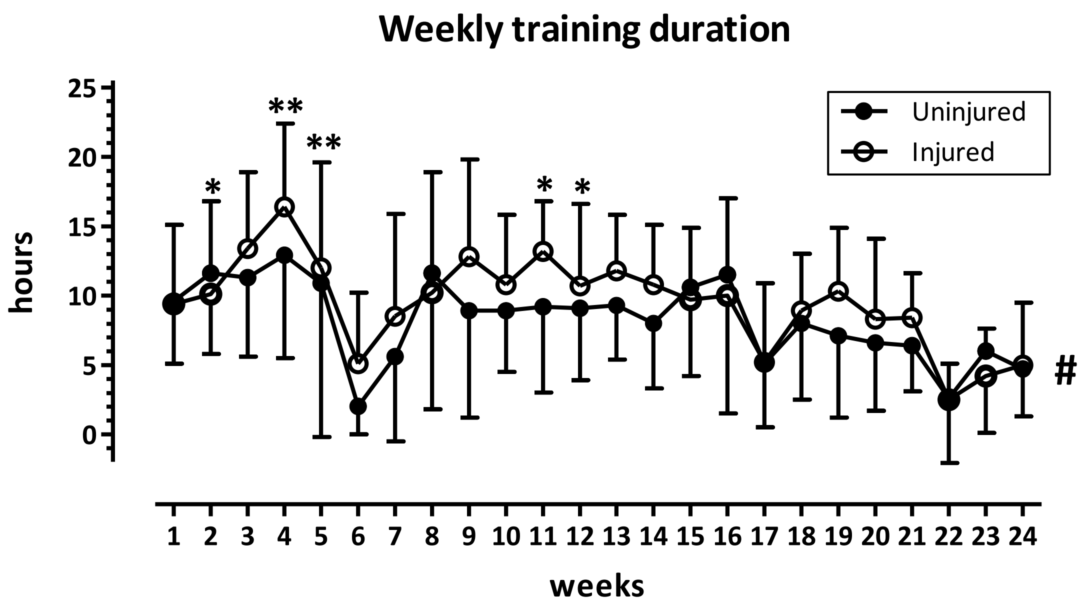

Figure 3.4: Total weekly training duration (h) of participants in the uninjured and injured groups for the 24-week study period. Data are expressed as mean ± SD.

Significant differences:

main effect of time (p = 0.021)

* week 2 vs. 22 (p = 0.012)

** week 4 vs. 6 (p = 0.001), 22 (p = 0.0003) and 23 (p = 0.004)

** week 5 vs 6 (p = 0.001), 22 (p = 0.0003) and 23 (p = 0.0003)

* week 11 vs. 22 (p = 0.026)

* week 12 vs. 22 (p = 0.037)

c) Weekly training distance

The weekly training distance of participants in the uninjured and injured groups over the 24-week study period is shown in Figure 3.5. There was a significant main effect of time for weekly training distance ($F_{(23,322)} = 8.4866$; p = 0.00001). Post hoc analysis showed that participants completed greater weekly training distances in week one compared to weeks six (p = 0.015) and 16 (p= 0.011); week two compared to weeks six (p = 0.002) and 16 (p = 0.001); week three compared to weeks six (p = 0.002) and 16 (p = 0.001); week four compared to weeks six (p = 0.00002) and seven (p = 0.002); week five compared to weeks six (p = 0.002) and 16 (p = 0.001); week six compared to weeks eight (p = 0.029) and 11 (p = 0.026); week eight compared to weeks 16 (p = 0.021) and 17 (p = 0.011); week nine compared to weeks 22 (p = 0.006) and 24 (p = 0.038); week 10 compared to week 22 (p = 0.014); week 11 compared to weeks 16 (p = 0.019) and 17 (p = 0.009); week 12 compared to weeks 17 (p = 0.038) and 22 (p = 0.002); and week 13 compared to week 22 (p = 0.024).

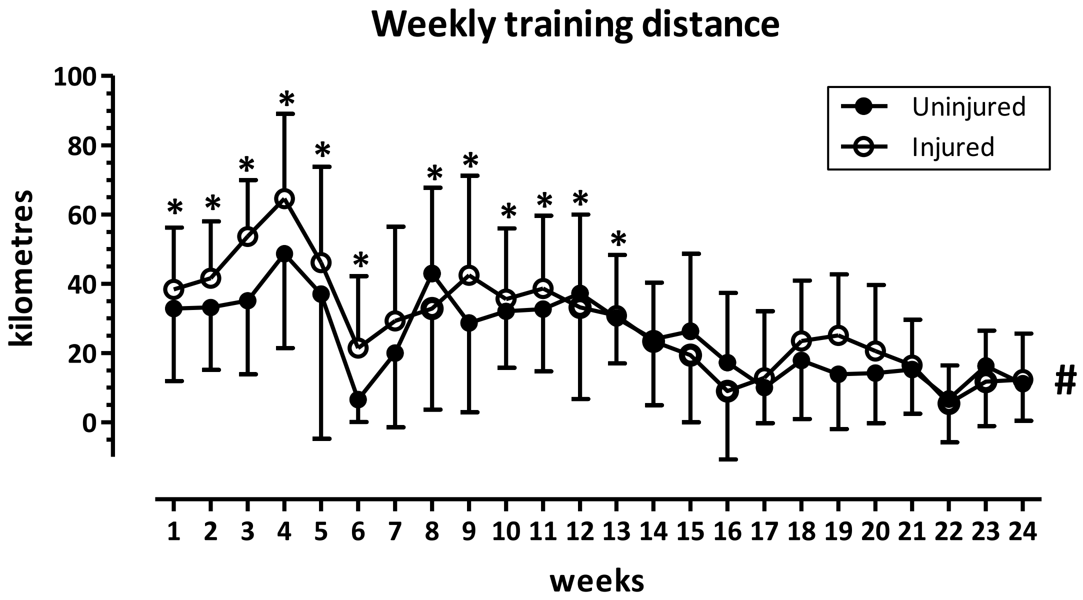

Figure 3.5: Weekly training distance (km) of participants in the uninjured and injured groups for the 24-week study period. Data are expressed as mean ± SD.

Significant differences:

main effect of time (p = 0.00001)

* week 1 vs. 6 (p = 0.015) and 16 (p = 0.011)

* week 2 vs. 6 (p = 0.002) and 16 (p = 0.001)

* week 3 vs. 6 (p = 0.002) and 16 (p = 0.001)

* week 4 vs. 6 (p = 0.00002) and 7 (p = 0.002)

* week 5 vs. 6 (p = 0.002) and 16 (p = 0.001)

* week 6 vs. 8 (p = 0.029) and 11 (p = 0.026)

* week 8 vs. 16 (p = 0.021) and 17 (p = 0.011)

* week 9 vs. 22 (p = 0.006) and 24 (p = 0.038)

* week 10 vs. 22 (p = 0.014)

* week 11 vs. 16 (p = 0.019) and 17 (p = 0.009)

* week 12 vs. 17 (p = 0.038) and 22 (p = 0.002)

* week 13 vs. 22 (p = 0.024)

d) Weekly training intensity

The weekly training intensity (rate of perceived exertion) of participants in the uninjured and injured groups over the 24-week study period is shown in Figure 3.6. There was a significant main effect of time for the weekly training intensity ($F_{(23, 92)} = 3.98378$; $p = 0.000001$). Higher rates of perceived exertion were shown in week one compared to weeks 17 (p = 0.005), 18 (p = 0.014), 21 (p = 0.023) and 22 (p = 0.001); week two compared to weeks six (p =0.037), nine (p = 0.037), 17 (p = 0.003), 18 (p = 0.008), 21 (p = 0.014) and 22 (p = 0.0004); week four compared to weeks 17 (p = 0.005), 18 (p = 0.014), 21 (p = 0.023) and 22 (p = 0.001); week five compared to week 22 (p = 0.008); week 11 compared to week 22 (p = 0.008); week 12 compared to weeks 17 (p = 0.037) and 22 (p = 0.005); and week 13 compared to week 17 (p = 0.005).

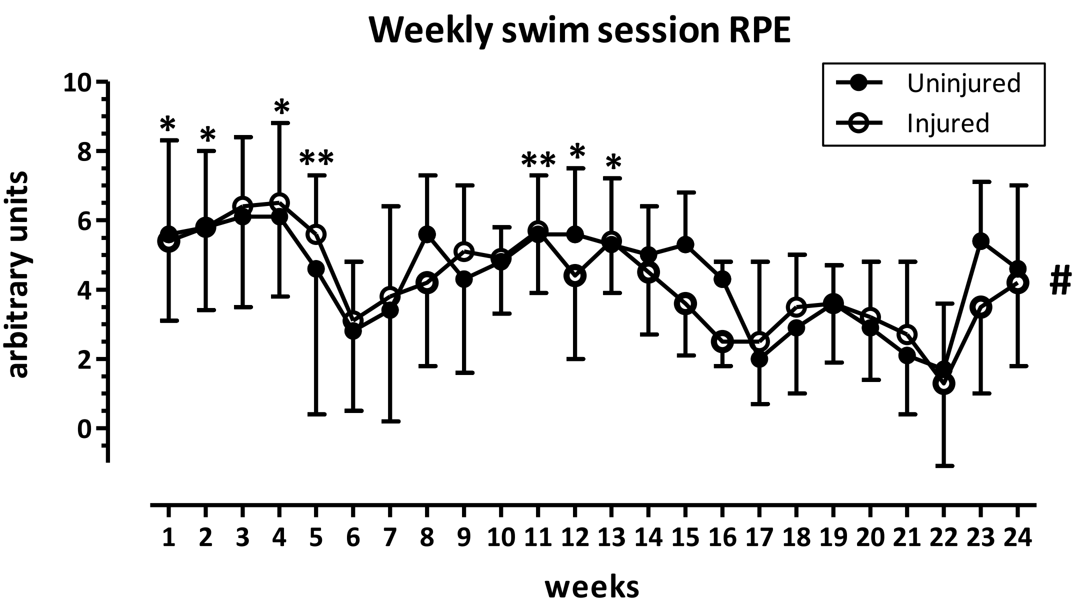

Figure 3.6: Weekly swim session RPE of participants in the uninjured (n = 9) and injured (n = 14) groups. Weekly rate of perceived exertion scores were recorded from week 0 to week for the 24-week study period. Data are expressed as mean ± SD.

Significant differences:

main effect of time (p = 0.000001)

* week 1 vs. 17 (p = 0.005), 18 (p = 0.014), 21 (p = 0.023) and 22 (p = 0.001)

* week 2 vs. 6 (p =0.037), 9 (p = 0.037), 17 (p = 0.003), 18 (p = 0.008), 21 (p = 0.014) and 22 (p = 0.0004)

* week 4 vs. 17 (p = 0.005), 18 (p = 0.014), 21 (p = 0.023) and 22 (p = 0.001)

* week 5 vs. 22 (p = 0.008)

* week 11 vs. 22 (p = 0.008)

* week 12 vs. 17 (p = 0.037) and 22 (p = 0.005)

* week 13 vs. 17 (p = 0.005)

3.3.4.4 Swimming competitions

There were no significant differences between groups for competitions attended. Participants completed a cumulative total of 192 competitions during the 24-week study period (Appendix 12). The individual average was worked out at 9.4 competitions per participant. The majority (76%) of competitions took place from weeks nine to 18. Participants did not take part in any competitive events during weeks three, 19, 23 and 24. The most competitions took place in week 13 (n = 38) and 14 (n = 22).

3.3.4.5 Cumulative dry-land training

There were no significant differences between injured and uninjured groups for cumulative dry-land training completed (Appendix 12). Participants in the uninjured and injured groups completed a cumulative total of 435 dry-land sessions during the 24-week study period. This was worked out at 21 dry-land sessions per participant for the study period, therefore n = 0.9 sessions per participant per week. The average duration of one dry-land session was 41 minutes (min). The cumulative duration of dry-land training for participants in both groups during the 24-week study period was 297 hours.

3.3.4.6 Participation in other sports

Participation in other sports was measured in athletic exposures (AE's). There were no significant differences between groups for the total participation in other sports. The sum of all 'other sport participation' was 131 AE's over the 24-week study period. The number of AE's for the main types of other sport were: athletics 43 AE's (32%), diving 18 AE's (14%), netball 18 AE's (14%), soccer 11 AE's (8%), squash 11 AE's (8%), ballet 10 AE's (8%) and waterpolo 4 AE's (3%).

3.3.5 Swimming injuries

3.3.5.1 Previous injury history

Seventeen participants (74%) reported having a previous musculoskeletal injury in the 12 months prior to study commencement. There were no significant differences in previous injury history between groups ($\chi^2 = 4.50$; $p = 0.61$).

3.3.5.2 Total injury incidence

The weekly self-reported injury incidence is shown in Figure 3.7. Fourteen participants sustained injuries during the 24-week study period, indicating a total injury incidence of 60.9%. Sixty injuries were sustained in total; 44 were recurrent and 16 were index injuries. The greatest number of injuries occurred in weeks four (n = 6) and 12 (n = 6).

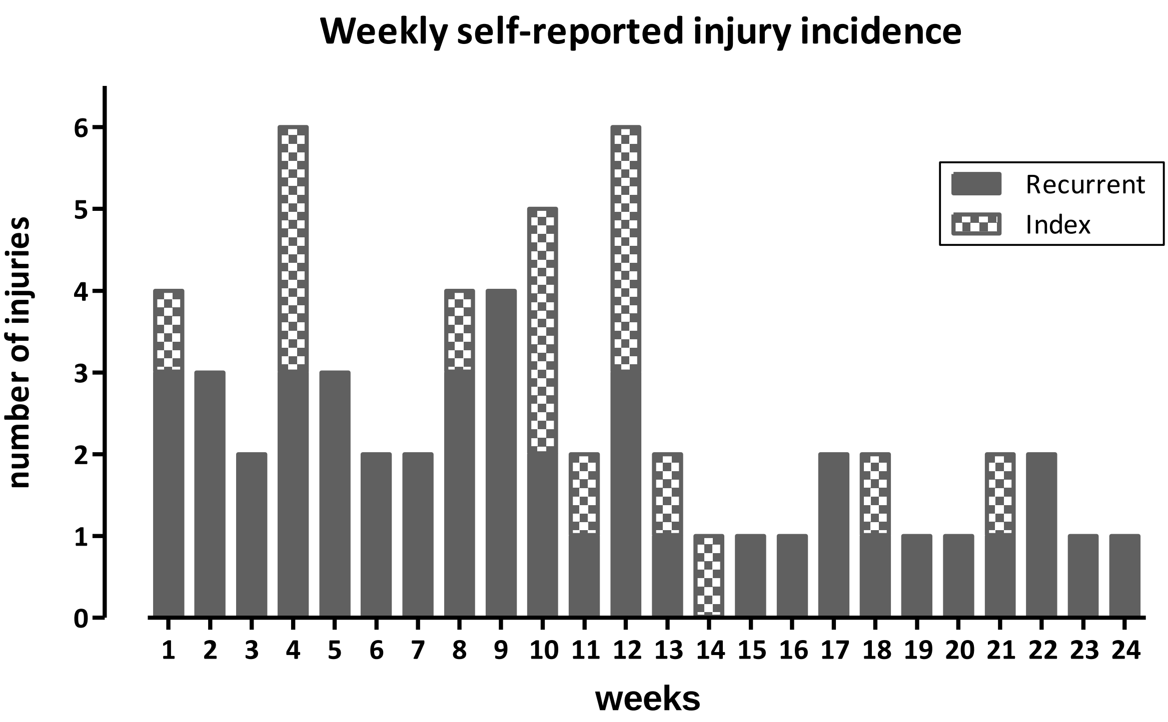

Figure 3.7: Weekly self-reported injury incidence depicting index and recurrent injuries of participants (n = 14) for the 24-week study period.

3.3.5.3 Injury incidence rate

Athletic exposures (AE's) were used to calculate injury incidence rate. Participants completed 2 683 AE's over the 24-week study period. There were 60 injuries recorded during this period.

Incidence rate was calculated by using the following formula:

$$[\Sigma \text{ injuries} / \Sigma \text{ exposure hours (AEs)}] \times 1\ 000$$

Therefore,

$$[60 / 2\ 683] \text{ x } 1\ 000 = 22.4$$

The incidence rate was calculated as 22.4 injuries per 1 000 AE's.

3.3.5.4 Injury location

The injury locations of participants (n = 14) are shown in Figure 3.8. The knee (n = 20) was the most common site of injury. This was followed closely by the shoulder (n = 19). The elbow (n = 9) and lower back (n = 8) ranked positions three and four respectively. Fewer neck (n = 3) and wrist (n = 1) injuries were recorded during the study duration.

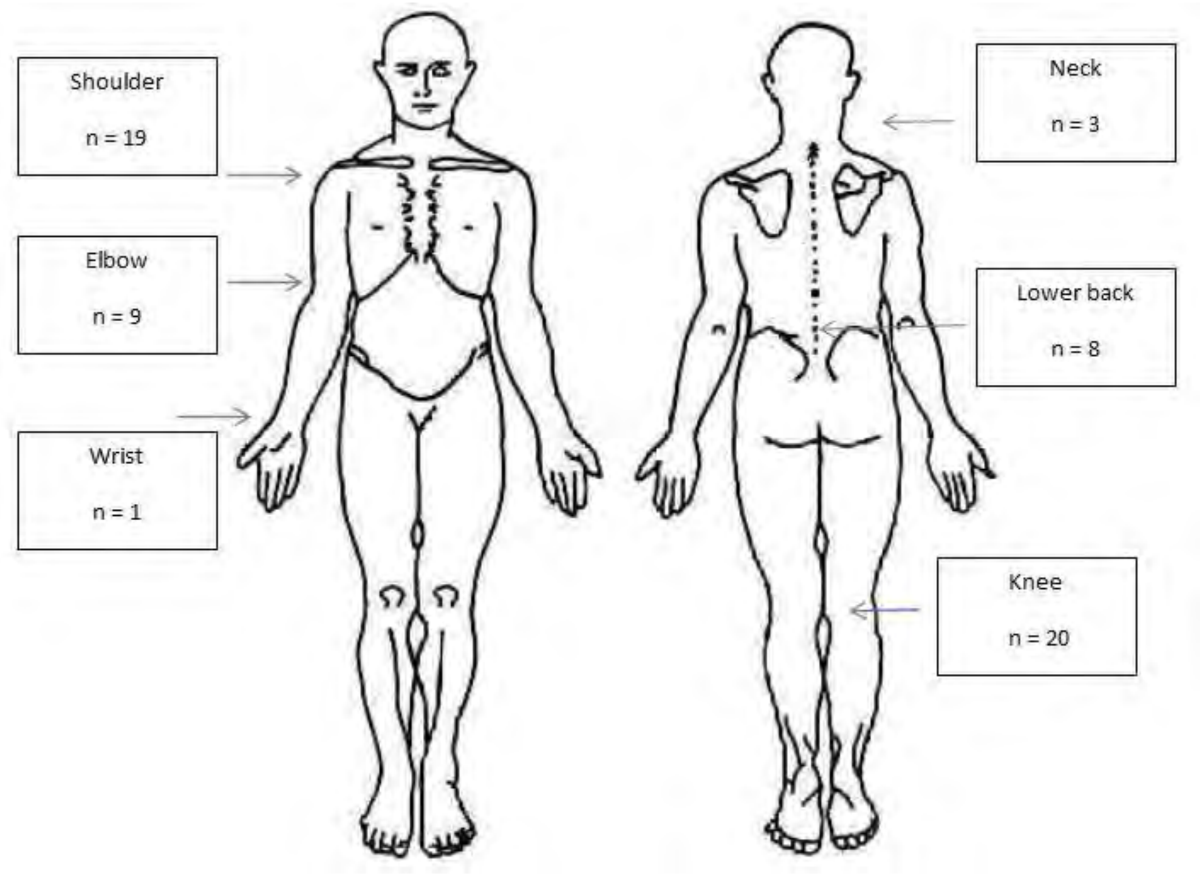

Figure 3.8: Injury locations (n = 60) sustained during the 24-week training period of this study. Data are expressed as numbers (n).

3.3.5.5 Mechanism of injury

Injured participants were asked to respond to the question of what activity they believed had caused their injury. Only one answer was accepted for this question. Most participants (n = 26) were unaware of what activity caused their injuries. Factors that were identified in contributing to injuries included: other sport participation (n = 13); swimming training (n = 12); dry-land training (n = 5); falls (n = 2); swim competitions (n = 1); and heavy lifting (n = 1).

3.3.5.6 Injury type

The study did not require that the type of injury be diagnosed by a medical professional. Participants were asked to identify the structure(s) they thought elicited their pain, hence the answers were subjective (Appendix 12). Muscle was listed as the main source of pain (n = 23; 38%). Other sources of pain included: cartilage (n = 9; 15%), joint (n = 7; 11%); tendon (n = 4; 7%); bone (n = 2; 3%); nerve (n = 1; 2%) and ligament (n = 1; 2%). However, a large number of participants were unable to identify the source of their pain (n = 13; 22%).

3.3.5.7 Factors aggravating pain during swimming

Injured participants were requested to report factors that aggravated their pain during swimming (Appendix 12). Although some participants reported no aggravating factors during swimming (n = 5; 8%), the following aggravating factors were identified by injured participants: pull buoys (n = 19; 32%); hand-paddles (n = 15; 25%); kickboards (n = 15; 25%); swimming drills (n = 3; 5%); and time-trials (n = 2; 3%).

3.3.5.8 Swimming training sessions modified or missed due to injury

Participants missed a total of 30 training sessions due to injury (95% CI's 0.32 - 22.56); and 22 swim sessions were modified due to injury (95% CI's 0.32 - 22.56). The highest number of missed sessions occurred in weeks one (n = 8) and 12 (n = 9); whereas the highest number of modified swim sessions (n = 9) occurred in week 4 (Appendix 12).

3.3.5.9 Treatment for injuries

Participants self-reported a total of 40 treatments for the injuries (n = 60) that occurred during the 24-week study period. Participants did not receive any treatment for approximately one third of the injuries reported in this study (n = 20; 33%). The following treatment options were reported by participants in this study: physiotherapy (n = 10; 16%); general practitioner/doctor (n = 8; 13%); massage (n = 8; 13%); self-management with rest (n = 7; 12%) and ice (n = 2; 3%); and chiropractor (n = 5; 8%).

3.3.5.10 Factors associated with increased injury risk

Odds ratios were calculated to determine potential factors that may be associated with an increased injury risk in this study cohort of adolescent swimmers. Descriptive, screening, and training and competition variables were analysed, and the results are presented in Table 3.12. Participants with a previous injury history were 7.5 times more likely to sustain an injury, compared to participants without any previous injury history.

In addition, participants who incorporated breaststroke training for less than 20% of their individual training hours were almost 13 times more likely to sustain an injury, compared to participants who spent ≥ 20% of training hours in breaststroke (Table 3.12). No other descriptive, screening or training and competition factors were associated with an increased injury risk.

Table 3.12: Potential factors associated with injury risk in participants (n = 23). Data are presented as Odds ratios and 95% confidence intervals (95% CI's).

Variable	Odds ratio	95% CI's	Significance
Descriptive characteristics			
Age (y)	1.44	0.28-7.21	NS
Mass (kg)	2.00	0.35-11.36	NS
BMI ($kg.m^{-2}$)	1.67	0.31-9.01	NS
Previous injury history	7.50	1.02-55.00	S
Gender	0.90	0.15-5.26	NS
Dominant hand	0.75	0.06-9.72	NS
Screening characteristics			
Total arc of motion deficit (°)	2.93	0.47-18.33	NS
GH internal rotation deficit (°)	2.63	0.39-17.46	NS
Beighton score (n)	1.40	0.20-9.87	NS
GH elevation (J)	4.58	0.73-28.65	NS
GH lift-off (J)	4.58	0.73-28.65	NS
GH horizontal abduction (J)	3.60	0.60-17.05	NS
GH external rotation (J)	2.93	0.47-18.33	NS
GH internal rotation (J)	2.25	0.41-12.44	NS
Knee flexion (J)	2.25	0.41-12.44	NS
Knee extension (J)	2.25	0.41-12.44	NS
Training and competition characteristics			
Other sport participation	0.46	0.04-5.26	NS
Freestyle swum during training (%)	4.58	0.73-28.65	NS
Breaststroke swum during training (%)	12.83	1.69-97.19	S
Hand paddle use / week (n)	1.63	0.09-29.78	NS
Cumulative training distance (km)	0.20	0.03-1.22	NS
Cumulative training duration (h)	0.60	0.11-3.24	NS
Cumulative time spent swimming competitively (y)	0.60	0.11-3.24	NS

Key: S – significant, NS – non-significant

3.3.6 Summary of results

In summary, the mean age for commencement of swimming training in both the injured and uninjured groups was approximately 7.5 years. Injured participants had significantly decreased subscapularis muscle strength ($p = 0.02$) relative to uninjured participants. The injured group also completed significantly higher average training session distances ($p = 0.04$) compared to the uninjured group. Fourteen participants (60%) sustained injuries during the 24-week study period. The injury rate was 22.4 per 1 000 athletic exposures (AE's). Sixty injuries were sustained in total; 16 were index, and 44 were recurrent injuries. The most common injury location was the knee joint (n = 20). The only factors associated with increased injury risk in this study were previous injury history (OR: 7.50; 95% CIs 1.02-55.00) and reduced percentage of time in breaststroke training (OR: 12.83; 95% CIs: 1.69-97.19). Swimmers with previous injuries were 7.5 times more likely to sustain injuries than swimmers with no previous injury history. The risk of sustaining an injury was approximately 13 times higher in participants who included breaststroke for less than 20% of their swimming training. Medium to large effect sizes were observed for musculoskeletal screening strength tests including: glenohumeral elevation and external rotation; lift-off; and knee flexion and extension. Few swimming training sessions were modified or changed due to injury, and the majority of injuries did not receive any treatment. These study findings will be discussed in the next section, together with the clinical implications of these research findings. The limitations of the study, as well as recommendations for future research, will also be highlighted.

3.4 DISCUSSION

Swimming is a popular form of exercise with many health benefits. In the last few years swim training programmes have added more pool sessions per week and increased the duration and mileage per session. The last few years have also seen an increase in injury incidence rate per 1 000 athletic exposures (AE's), from 2.12 in 1996 to 5.95 in 2013[30]. The majority of studies have investigated injury incidence in adult swimmers. There are limited prospective studies on adolescent swimmers. Therefore, the aim of this study was to determine the incidence of injuries in an adolescent swim squad, and to determine whether there were any factors associated with an increased risk of injury. The results of this study will be discussed in the following sections, and will follow the order in which results were presented in Section 3.3.

3.4.1 Descriptive characteristics

3.4.1.1 Demographic and historical training and competition characteristics

There were no significant differences between groups in demographic characteristics (Table 3.5). The mean age for commencement of swimming training in both the injured and uninjured groups was approximately 7.5 years. This age provides evidence for the theory of early specialisation (Section 2.6.2.6, page 32), which stipulates that children are to begin training at young ages so as to excel in a particular sport[92]. It is thought that specialised training, commencing only in later years, places children/adolescents at a disadvantage because they are not able to catch up to others who began developing expertise earlier[92]. The consequence of early specialisation is that training occurs during a time of important biological development which may stunt physical, social and psychological growth[92]. Dalton et al.[96] found that excessive training loads during the growth phase increases risk of overuse injuries in adolescent athletes[96]. The age of competitive swimming commencement was, however, not found to be a risk factor in the current study.

There was a significant difference between groups in the amount of breaststroke swum during training (Table 3.6), with the injured group incorporating significantly less breaststroke training compared to the uninjured group. In addition, participants who incorporated breaststroke training for less than 20% of their individual training hours were almost 13 times more likely to sustain an injury, compared to participants who spent ≥ 20% of training hours in breaststroke (Table 3.12). It seems that a greater percentage of breaststroke training might have a protective effect, particularly as there was no association between relative percentages of training in other swim strokes and injury risk. However, it is recognised that this finding conflicts with earlier studies, which showed associations between medial knee pain and breaststroke[148,149].

This study was unable to establish any potential mechanisms associated with the proposed “protective effect” of breaststroke swimming in adolescent swimmers. It is also unclear whether this protective effect was afforded to any specific area of injury. Further studies are needed to examine this phenomenon in more depth. Interestingly, previous studies have demonstrated that an increase in freestyle training was associated with shoulder injuries[20,79,150]”. Interestingly, previous studies have demonstrated that an increase in freestyle training was associated with shoulder injuries[20,79,150].

3.4.2 Baseline screening tests

In this study, there was a significant difference between groups in the lift-off test, with lift-off strength being significantly reduced in the injured group compared to the uninjured group (Table 3.10). There were no other significant differences between groups for any other musculoskeletal screening tests (Tables 3.9 and 3.10). However, medium to large effect sizes were observed for some screening strength tests including: glenohumeral horizontal abduction, internal rotation, elevation, external rotation, and knee flexion and extension.

Pink et al.[151] found that subscapularis continuously fired above 20% of its maximum in swimmers with normal shoulders[151]. Conversely, subscapularis firing activity was reduced in swimmers with painful shoulders[151]. The same authors determined that there was no difference in latissimus dorsi and pectoralis major muscles when comparing injured and uninjured shoulders. Therefore, they concluded that shoulder injury prevention strategies need not focus on strengthening latissimus dorsi and pectoralis major muscles, as they did not play an integral role in causing shoulder injuries in swimmers. Similarly, the same study also found no difference between painful or normal shoulders in muscle activity of the following: supraspinatus, teres minor and posterior deltoid muscles[151]. These findings could explain why there were no differences between groups for any of the musculoskeletal strength tests, except for lift-off tests (Table 3.10).

The test results were not statistically significant, but suggest clinical relevance. The results suggest that the current study population might benefit from a conditioning programme that focusses on improving strength in deltoid, teres minor and infraspinatus muscles, plus all previously mentioned internal rotators.

While Pink et al.[151] suggest that subscapularis and serratus anterior are the major muscles to be included in a prevention program[151], in this study there was weakness of other muscles including deltoid and the external rotators at baseline testing.

Medium effect sizes were observed for knee flexion and extension strength tests, with muscle strength consistently reduced in the injured group compared to the uninjured group. It was also noted that in this study, the most common site of injury was the knee joint (Section 3.3.5.4, page 86). However, there were no associations between knee muscle strength and the risk of injury. In addition, in this study there were no associations between musculoskeletal screening tests and injury risk. The findings of the current study therefore do not support findings of other authors that described muscle imbalance and/or weakness as potential risk factors for injuries in both the general adolescent population and adolescent swimmers[8,27,42,83]. Further research is needed to establish if these findings apply in larger samples and if the weakness is related to a history of previous injury.

3.4.3 Training characteristics

3.4.3.1 Individual and weekly swim sessions and cumulative training

In this study, there were no significant differences between groups for many training characteristics including: cumulative training distance and duration (Table 3.11); average session duration (Figure 3.1); number of weekly swim sessions (Figure 3.3); weekly training duration (Figure 3.4); weekly training distance (Figure 3.5); and weekly training intensity (Figure 3.6). Training loads were self-reported and thus subjective, which may limit the accuracy of reporting. Only average session distance (Figure 3.2) showed a significant difference between groups. The injured group swam consistently greater distances per swim session than uninjured participants. Previous studies on adolescent athletes found that increased training exposure and hours spent training, increased risk for injury[8,11,27,34,50]. This was not supported by findings of this study; this could be because previous studies had larger samples, longer follow-up periods and investigated a variety different sports. Additionally, the current study coincided with the mid-season of a year-round sport; perhaps investigating the association between swimming training loads and injuries in the pre- or off-season would yield different results.

Significant main effects of time were observed for a number of training variables, namely: average session duration, number of weekly swim sessions, weekly training duration, weekly training distance and weekly training intensity.

However, it was not possible to identify any specific pattern to changes in training loads during the 24-week study period, and the variations in training loads were inconsistent in terms of volume, duration and intensity. It is possible that the variations in training loads and intensity might have been associated with changes in the academic school calendar rather than with achieving a specific training goal. From this 24-week longitudinal study it appeared that periodisation both at macro- and micro-levels was poorly applied. Periodisation in adolescent sport is beneficial in preventing over-training and reducing risk of injuries[90,152]. It appears that the principle of specificity was also not applied because participants reported similar training volumes and intensities in training as part of a team. Section 2.6.2.4 (page 30) explained the difficulty of applying the principle of specificity at high-school club level (large numbers of swimmers, few coaches overseeing training sessions and compliance with swimming programmes). A lack of periodisation and specificity could potentially increase risk when considering factors like maturity associated variation and age (Section 2.6.2.1 b) and Section 2.6.2.2, page 29).

The large standard deviations and CI's for cumulative training distance and duration indicate that these results should be interpreted with caution and are unlikely to be a true representation of the cumulative training loads. Larger sample sizes would provide more accuracy in determining cumulative values. A systematic review by Gaunt et al.[27] mentioned that training in swimmers ranged from nine km per week at club level to 110 km per week at international level[27]. A study interviewing 97 swim coaches from different clubs throughout the United States of America found that swimmers aged 11 to 14 trained approximately 5 to 15 hours per week and swam less than 23 km[84]. Swimmers aged 15 to 18 trained 11 to 20 hours per week and training distance ranged from 23 to 37 km per week[84]. Findings of this study reported similar training volumes within that range.

3.4.3.2 Competitions per week

Competitions took place mostly during school terms, again coinciding with the academic school year. According to Section 3.3.4.4 (page 84) each participant competed in an average of 9.4 competitions in 24 weeks. The average accounted for participants lost to follow up at various points during the study (Section 3.3.1, page 70). This equates to individual participants taking part in approximately one competition every three weeks. One competition could include numerous individual swimming events, meaning that several competitive events grouped together may not provide an accurate indication of competition load. The individual competition load for adolescent swimmers in this study appears to be high relative to the weeks of follow-up.

No literature was found providing information on the 'normal' ranges for competition loads in adolescent swimmers. One study investigating injury incidence in 34 collegiate competitive swimmers determined a cumulative total of 379 competitions over eight months[30]. The longer follow-up period, adult age and the high level of competition account for the high number of competitions in that study compared to the current one.

3.4.3.3 Cumulative dry-land training

Participants completed a cumulative total of 435 dry-land sessions over the 24-week study period (Section 3.3.4.5, page 84), which equated to an average of 21 sessions per participant for the study period. The average session duration for dry-land training was 41 minutes (Section 3.3.4.5, page 84).

Dry-land training forms an integral part of many competitive swim training programmes, yet limited literature exists on the topic, especially in young swimmers[84,153]. Ninety-seven swim coaches in the USA were asked to complete a survey about dry-land training. Fifty to 93% of these coaches confirmed the use of dry-land training to supplement their swim programmes[84]. It was suggested that dry-land training benefits included injury prevention and swimming performance enhancement[26]. Other studies also found dry-land sessions to have positive effects on swimming performance[105,106,153], with two sessions of maximal strength training per week being sufficient to improve swimming performance[153]. This value is more than double the amount of sessions completed by swimmers in the current study. Other authors, however, found no benefit for swimmers partaking in dry-land training and stated it would be more valuable for swimmers to complete 'swim-specific' strengthening in the water[10,107]. Therefore, evidence regarding the potential benefits of dry-land training for swimmers[84] is conflicting. This inconclusive research has made it difficult to determine appropriate modes, frequencies or intensities of dry-land programmes in adolescent swimmers.

Krabak et al.[84] mentioned that the main reason swimmers did not attend dry-land training was limited practice time[84]. In the current study, swimmers were instructed to perform cardio exercise as a warm up. They were also required to complete strength training, alternating between arms and legs each week (personal communication with Coach Williams). It was evident that no real structure was given to dry-land sessions and participants were able to choose freely between activities. There was also no specific guidance regarding the number of repetitions, sets and level of difficulty of any particular exercise.

The trend seems to be that young swimmers use predominantly body weighted exercises combined with cardiovascular training; with increasing age introducing the use of machine and free weights[84]. These findings concur with those of Krabak et al[84] who stated, *"No clear guidelines exist regarding the athlete's age for initiating dry-land training or the types of exercises that constitute an ideal dry-land training program* [84(p303)]*"*. This is clinically important because dry-land training, when structured properly and tailored to suit individual needs, could potentially minimise injury risk[84]. Future studies that evaluate the effects of dry-land training on injury risk and swimming performance are needed.

3.4.3.4 Participation in other sports

In this study, only 27% of participants took part in other sports. The theory of early specialisation, referring to the 'catch them young' philosophy[21,92] was discussed in Section 2.6.2.6, (page 32). Swimmers in this study were actively discouraged from taking part in other sports. It seems that the swim squad coach had a strong belief that participation in other sports might negatively influence swimming performance and increase injury risk (personal communication with Coach Williams). However, it is recognised that this only represents the opinions of the coach, as this study did not investigate individual participants' reasons for taking part in other sports. Baxter et al.[70] observed that in young elite athletes taking part in four different sports, including swimming, more than half the injuries were caused by some other sporting activity[70]. However, in this study, there was no association between participation in other sports and injury risk (Section 3.3.4.6, page 84).

3.4.4 Swimming injuries

3.4.4.1 Previous injury history

In this study, seventeen participants reported a previous injury history in the 12-month period prior to study commencement (Section 3.3.5.1, page 84). This equates to a 'historical' injury incidence of 74%, which is high considering the relatively young age of participants. In addition, participants with a previous injury history were 7.5 times more likely to sustain an injury, compared to participants without any previous injury history (Table 3.12). Previous injury history is one of the most commonly identified risk factors for future injury[11,32,154] (Section 2.6.2.7, page 32). Risk was specifically identified for adolescents participating in a variety of different sports [11,12,34,41,154]. Emery et al.[34] observed that 47% of index injuries in a sample of 1 466 adolescents were attributed to previous injury history at the same location[34].

Walker et al.[41] investigated shoulder injuries in adolescent/adult swimmers[41]. They found that participants with previous injury history were 4.1 times more likely to exhibit significant interfering shoulder pain (SIP) and 11.3 times more likely to have a significant shoulder injury (SSI)[41].

Previous injuries can cause fibrosis at the injury site leading to adhesions and restricted joint range of motion (ROM)[12]. This increases the potential for injury at the same location in future[12]. Other areas of the body are also at higher risk for index injuries because of the compensatory mechanism resulting from the reduced ROM and muscle atrophy[12].

It is recognised that there is the potential for recall bias in the reporting of previous injury history[155]. Previous sports injury studies also used a 12-month recall period in an attempt to reduce recall bias[155,156], and therefore the same reporting period was selected for previous injury history in this study. It is possible that participants may either not have remembered an injury incident, or whether the incident was 'swimming-related'. Participants may also have experienced difficulty in discerning between an injury and delayed onset of muscle soreness. These factors may have contributed to over-reporting or under-reporting of previous injury history, and this limits the interpretation of previous injury history.

Identification of previous injury history as a risk factor has important clinical implications. It highlights the need for appropriate screening and prevention programmes in young swimmers[34]. Musculoskeletal screening for adolescent swimmers should be modified to assess intrinsic and extrinsic risk factors specific to swimming as a sport. Future studies could include more functional screens like the Penn shoulder score[157], and modified versions of the Functional Movement Screen (FMS)[158–161] and/or Functional Lower Extremity Evaluation (FLEE)[162]. Prevention programmes should be aimed at increasing overall muscular and core strength. Furthermore, since previous injury history was established as a risk factor in this study, the correct management and rehabilitation of index and recurrent injuries could significantly reduce injury incidence in adolescent, competitive swimmers.

3.4.4.2 Total injury incidence and injury incidence rate

In this study, 14 participants sustained injuries during the 24-week study period, indicating a total injury incidence of 60.9%. Participants in the injured group sustained a total of 60 injuries. Of the total injuries, 44 were recurrent, while 16 were index injuries. However, it is difficult to draw direct comparisons between this study and previous studies, due to differences in variables such as the study period, the age and level of experience of the swimmers, and differences in study design. Chase et al.[30] determined injury incidence at 59% during their 8-month study period[30]. Over a five-year study period Wolf et al.[29] declared injury incidence at 73% in males and 70% in females[29].

A further study that evaluated musculoskeletal injuries in adolescent, elite swimmers, found an injury incidence of only 32%[38], which is considerably lower than that of the current study. However, this was a retrospective study with a much larger sample size (n = 149) than that of the current study[38]. In addition, there was no clear definition of the term 'sport's injury' was provided[38]. Therefore, if like other studies, classification entailed diagnosis by a medical professional[4,17,65,66] or missing at least one practice session[4,7,50,65], then comparatively fewer injuries would have been reported overall.

However, there are notable differences in injury incidence rates between the current study and previous studies. The overall injury incidence rate in this study was 22.4 per 1 000 AE's; whereas previous studies have reported overall incidence rates of 2.1[30], 3.6[29] and 5.9[30] per 1 000 AE's respectively. However, previous studies were conducted investigating adult swimmers[29,30], and the study investigator was unable to find any previous research studies that reported injury incidence rates in adolescent swimmers. The only previous study that reported injury incidence rates in adolescent athletes was a study that examined North American high-school athletes who took part in a variety of land-based sports[163].An overall injury incidence rate of 2.5 per 1 000 AE's was reported[163], which is also significantly lower than the current study. It is difficult to account for these discrepancies in incidence rates. It is possible that, as this study sample was restricted to one swim squad, swimmers were exposed to similar training regimes and competition loads. Decreased variance in exposures might account for overall increased risk for injury. However, no training or competition factors were associated with increased injury risk in this study. In addition, swimming involves extensive training year-round without any real off-season, meaning athletes are not given sufficient time to recover. A lack of adequate periodisation might also contribute to increased injury incidence rates in adolescent swimmers[90].

Importantly, however, perhaps the high injury incidence rate observed in this study is simply reflective of the increased vulnerability of adolescent athletes to injury. As was described in Section 2.6.2.1 (page 28), young athletes' biological development is very rapid. This increases physical vulnerability due to the non-linearity of growth and imbalances between bone, tendons, cartilage and muscles (Section 2.6.2.1, page 28)[64]. Parents and coaches (Section 2.6.2.5, page 31) may further negatively influence injury incidence if unaware of these physical risk factors specific to adolescents[21,90]. Early specialisation (Section 2.3.2.6, page 32) with excessive training loads also appears to have negative consequences for continued physical and psychological growth[21,97].

The clinical implication is that there is a need for education on adolescent specific risk factors for coaches, swimmers and their parents. Education would increase awareness on the potential danger and could assist in ensuring training loads and competition exposures are age-appropriate.

Furthermore, in this study recurrent (overuse) injuries were more common than index (new/acute) injuries. Seventy-three percent of injuries were recurrent. Previous studies have also identified a high occurrence of recurrent injuries in swimmers, with 50% to 60% of injuries being reported as overuse injuries in three studies[30,43,164]. The findings of this study suggest that adolescent swimmers might be more susceptible to recurrent injuries. As discussed in Section 2.6.2.1(page 28), the 'skeletal uniqueness' of young athletes increases vulnerability to repetitive micro-trauma, particularly during periods of rapid growth[36,64,70,165].

3.4.4.3 Injury location

The current study determined that the knee (33%), shoulder (32%), elbow (15%) and lower back (13%) were the most common sites of injury. In general, most previous studies have identified the shoulder as the most common injury site in adult swimmers, with prevalence rates of 31% and 39%[26,27,29,30]. These studies also report a low prevalence (below 15%) of knee injuries[26,27,29,30]. Sambanis et al.[38] also reported the shoulder to be the most common injury site (69%) in adolescent swimmers[38]. In contrast, they identified the knee as the second most common injury site[38]. It therefore seems that adolescent swimmers may have a greater predisposition for knee injuries than adults. The reasons for this include factors that have been previously explained in Section 2.6.2.1 (page 28). The knee is a common sight of apophysitis (Osgood-Schlatter disease)[36,58,64] in young athletes (Section 2.6.2.6, page28).

The patellofemoral overload results from repetitive knee flexion, extension and quadriceps contraction during kicking[75,77]. High patellofemoral contact stresses are additionally caused by pushing off the wall[77]. Knee injuries are also thought to occur from incorrect kicking techniques[75,77]; perhaps adolescent swimmers' technique is not yet as skilled or energy-efficient as their adult counterparts.

In addition, previous studies have also identified the lower back as a common injury site, with comparable prevalence data of between 16%[30] and 22%[26,29]. Wolf et al.[29] combined back and neck injuries, which possibly resulted in the slightly higher reporting of back injuries[29]. The results of the current study indicate a need for education on back care in young swimmers.

Clinical implications include provision of prehabilitation 'core strengthening' programmes with particular focus on conditioning the lumbar spine. Lumbar strengthening exercises incorporating the use of body weight, therabands, and light free-weights could also be performed as part of dry-land training to supplement swimming training in-season. A screening tool like the Micheli Functional Scale (MFS)[166], valid for assessing lower back pain and functional status in young athletes, could be modified to assess swimmers. Furthermore, reducing hyper-extension of the lumbar spine by modifying kicking techniques and reducing the use of training devices (e.g. fins and kickboards) would assist in prevention of lumbar spine injuries[26,64,89,151]. Prevention of lower back injuries in young athletes is imperative because lower back pain during the adolescent phase has been associated with lower back pain in future adult years[167–169].

There was a relatively high occurrence of elbow injuries in this study. Wolf et al[29]. reported a 14% prevalence of combined elbow, wrist, hand and finger injuries[29]. This suggests that there might be an increased susceptibility to elbow injuries in adolescent swimmers. As discussed in Section 2.6.2.1 a) (page 28), adolescents in general are prone to apophysitis at the elbow. Similar to the knee joint, flexor tendons exhibiting increased strength and attaching to the medial epicondyle, exert tensile forces at this joint[36]. The elbow, like the shoulder, additionally experiences high tension stresses due to the repetitive nature of the swimming stroke[26,27].

3.4.4.4 Mechanism of injury

Participants were requested to choose an activity which they thought had triggered their injury. Most participants (n = 26) were unaware of what activity caused their injuries. Factors that were self-identified in contributing to injuries included: other sport participation, swimming training, dry-land training, falls, swimming competitions, and heavy lifting. Baxter-Jones et al.[70] stated the following reasons for sustaining more injuries during other sport participation: *"poor quality playing fields, inappropriate protective equipment, and inefficient supervision by well-meaning but untrained people with limited knowledge of sports physiology and the treatment of sports injuries*[70(p132)]*"*.

Two studies investigating adolescent general sport participation found that the number of injuries sustained during competitions were high[11,163]. Kutz et al.[90] mentioned that competitions were one of the main causes of injury in adolescent swimmers[90]. This study did not support those findings, possibly because the cumulative number of competitions was low relative to competitions in other sports. Additionally, injuries during competitions in land-based sports may be index (acute) injuries, whereas the majority of injuries in this study were recurrent (overuse). However, all the answers to this question were self-reported, thus subjective, and may not necessarily have reflected reality.

3.4.4.5 Injury type

In this study, participants were asked to self-identify the structures they thought elicited their pain, hence the answers were subjective. Muscle was listed as the main source of pain (38%), followed by cartilage (15%) and joint (11%). However, approximately 22% of participants were unable to identify the source of their pain. The high proportion of participants that were unable to identify potential involved structures suggests a low level of health literacy regarding injuries. Although this might not be considered unusual in an adolescent population, the study cohort was a group of highly-trained, competitive swimmers. Improving health literacy generally, and injury knowledge specifically, might contribute to better understanding of injuries, and improved compliance with injury management[56,170]. However, further studies are needed to confirm levels of health literacy in adolescents taking part in competitive sports.

3.4.4.6 Factors aggravating pain during swimming

In this study, participants identified the use of pull buoys, hand paddles, and kick boards as factors that aggravated pain during swimming. Pull buoys were reported to be the biggest aggravators of pain, documented 19 times (Appendix 12). Pull buoys (a floating device secured between the upper thighs), are used so that swimmers can focus on upper limb strengthening, freestyle stroke technique and increasing rotation speed[9]. The legs are completely eliminated from aiding forward propulsion. Hence, increased strain is placed on the upper limbs, risking aggravation of existing shoulder and elbow injuries. Therefore, participants with these injuries would most certainly have reported increased discomfort on using pull buoys.

Hand paddles were associated with injury aggravation 15 times in the current study. Hand paddles are perforated plastic plates placed over swimmers palms and attached to the dorsal aspect with elastic bands[9]. Paddles increase the surface area of hands, thus allowing for faster and better propulsion through water. The resistance felt by the upper limb is greater, thus imposing increased loads on it. Hand paddle use may exacerbate pain if the hand enters the water at an incorrect angle due to faulty technique or fatigue. This causes a greater twist moment on the arm[66]. Most swimmers in this study reported using hand paddles during training once to twice a week.

Kickboard use aggravated a total of 15 injuries (Appendix 12). Using a kickboard means the arms are completely eliminated from forward propulsion. Knees injuries were the only lower limb injuries in the current study, meaning that constant kicking significantly exacerbated these. Constant kicking could quickly lead to fatigue, a risk factor for leg injuries. Fatigue could also result in incorrect wall push-off, allowing sub-optimal forces to be transmitted through an already injured lower limb. Kickboard use could, however, also have non-desirable effects on other body parts. While holding the kickboard, shoulders are fully flexed causing a reduction in the sub-acromial space. This could aggravate impingement syndromes resulting in shoulder pain. Simultaneously the lower back and neck are hyperextended when keeping the head above water. These positions have the potential to flare up existing shoulder, lower back or neck injuries.

Drills exacerbated three injuries; the repetitive element of performing drills is what likely caused the increased discomfort. Time trials exacerbated three injuries indicating that only a small number did not respond well to maximum speed.

In summary, participants perceived equipment to aggravate their injuries considerably more than either time-trials or drills. This supports the notion of various authors that these training factors should be used cautiously by coaches so as not to increase injury incidence in swimmers[26,65]. It would be beneficial for future research to focus on these training adjuncts not only as injury aggravators, but also as potential risk factors for injuries.

3.4.4.7 Swimming training sessions modified or missed due to injury

Participants missed a total of 30 training sessions due to injury; and 22 swim sessions were modified due to injury (Appendix 12). In comparison to the overall injury incidence, the number of modified or missed swimming sessions is low. This poses the question of whether injuries are accepted as such a normal part of swimming training and competition that training loads were only minimally adjusted as a result. This could potentially contribute to the high number of recurrent injuries (n = 44) reported during the study period.

These data again highlight the need to improve health literacy in coaches, participants and parents[56,170]. Education on risk factors, injuries and management thereof would increase understanding of why rest and recovery play such an important role in facilitating injury healing. This would incorporate information about the phases of healing and the negative consequences of returning to sport prematurely.

The inflammatory phase is vital to protect the injury site and establish a fibrin network[58,171]. During the fibroblastic (regeneration) phase, laying down of collagen promotes a connective tissue scar[171]. Clinically, it is important that return to sport is modified during the remodelling phase so as to promote scar formation that is both sufficiently strong and flexible to reduce the risk of re-injury to the same location[58,171].

3.4.4.8 Treatment for injuries

The majority of injuries did not receive any treatment and participants continued swimming throughout any discomfort felt. As mentioned in Section 3.3.5. (page 87) this again implies that injuries are accepted as a normal part of training, since swimmers did not regularly seek treatment despite being part of a supervised training squad. The large number of injuries relative to treatments received again questions whether young swimmers are given sufficient and/or correct information regarding injury prevention and management. Since minors require guidance with regards to estimation of injury severity and the need for treatment, poor health literacy in coaches and parents could be a contributing factor.

Treatments have financial implications which also require parents to be informed about injury severity. Thus, injuries not considered 'serious' enough to impact swimming performance may not have received treatment.

Physiotherapists were the medical professionals consulted most frequently. 'Rest' as a form of treatment, was only reported twice. This indicated a large discrepancy between 'rest' and the number of 'missed swim sessions' (Appendix 12), as more missed sessions were reported due to injury. A potential reason for this could be that participants only considered rest to be treatment when instructed to do so by a health care professional or massage therapist. Alternatively, perhaps participants had already reported one form of treatment (for example physiotherapy), and may not have thought to additionally document further treatments when completing the questionnaire. Similarly, perhaps ice was used in conjunction with other forms of treatment, but was only documented if participants used it in isolation. Future studies could include recording the number of treatments received per injury and why particular treatment methods were chosen to improve the outcome of this section.

3.4.5 Limitations of the study and recommendations for future research

It is recognised that the main limitation of this study was the sample size, and that this limits the generalisability of the study findings. However, we took a pragmatic decision in designing the study. On balance, we decided that it would be preferable to include swimmers from clubs where the study investigator had an existing relationship with the swim coaches, in an attempt to improve the acceptability of the study.

Therefore, only one swimming club was used to obtain the sample population, hence there were limited numbers of swimmers who met the inclusion criteria and were prepared to volunteer. All injury and training data were self-reported, hence subjective, and may have limited accuracy in prediction of risk factors for injury[155].

Another limitation was participants' young age, which anecdotally, may have resulted in reduced compliance in completing training and injury logbooks. Swimmers of school-age likely have additional responsibilities like academics, extracurricular activities and social engagements. It appeared that participants were more likely not to complete the online log during exam periods in the school calendar, or peaks in swimming training or competition loads. At times, the online training log was submitted one or even two weeks late, which introduced recall bias. This occurred despite regular reminders being given to participants. An eight-week study on adolescent students found the provision of incentives (financial incentives, internships, prizes and leadership opportunities) greatly increased retention rates[172–174]. Providing incentives is an important consideration for future studies investigating injuries in young swimmers, as this would help to increase sample size and potentially allow for longer follow-up periods[174].

A limitation was evident in a lack of the swim coaches' engagement in the research study. This made it difficult to confirm important training data and performance variables (e.g. time trial data) were thus removed from the study. In addition, there was an unanticipated setback when the online injury report and training questionnaire needed to be changed between 16 and 17 weeks. The initial online log was uploaded onto ©Fluid Survey. The new online tool needed to be converted manually to suit the ©Survey Monkey format. This process, together with updating of subscription fees resulted in a delay of five days in sending the survey out. The delay coincided with an important swim gala and term exams. This combination of factors meant that three participants did not submit weekly surveys thereafter, and these participants were lost to follow-up.

Recommendations for future research include more standardised injury and training reporting. More objective data would be obtained if this information were provided by coaches and medical support staff[155]. Future studies should aim to increase the study period to allow for longer follow-up through all components of the swimming season. Another recommendation is to increase sample size and perhaps include participants from two or more swim squads.

Future research could include an intervention control group where coaches and/or participants are educated on injuries in adolescents and prevention thereof. Injury incidence, severity and swimming performance could then be compared between groups. Similarly, future intervention studies could evaluate the effect of pre-season screening and/or provision of strengthening programmes on injury incidence.

CHAPTER 4: SUMMARY AND CONCLUSION

Competitive swimming popularity has increased in recent years[8,26,27], and this has been associated with increased reporting of swimming-related injuries[8,29]. The pubescent growth phase is associated with risk factors that may influence adolescent swimmers' susceptibility to injury[11]. Injuries in adolescent athletes may also have a significant impact on future sports participation and quality of life in adulthood[11,35]. No studies have prospectively evaluated risk factors for injuries in competitive, young swimmers. Therefore, the overall aim of this study was to determine injury incidence and potential risk factors for injury in adolescent swimmers over a 24-week period. Based on the evidence provided in this dissertation, the study objectives as described in Section 1.2.2 (page 2) may be answered as follows:

To describe the demographic and training characteristics of competitive adolescent swimmers

The mean age for commencement of swimming training in both the injured and uninjured groups was approximately 7.5 years. Injured swimmers had higher average swim session distances compared to uninjured swimmers. Overall, there was a high degree of variability in weekly and individual swim session training loads, which suggests poor periodisation. While it was not possible to elucidate any specific training-related risk factors for injury, adequate periodisation is a key consideration for adolescent swimmers. Swimmers, parents and coaches should be educated to ensure the application of age-appropriate training loads, with adequate periodisation to ensure appropriate recovery, to minimise injury risk and to maximise exercise performance.

To establish the incidence and nature of self-reported swimming-related injuries in competitive adolescent swimmers

Fourteen participants (60%) sustained injuries during the study period. The injury rate was 22.4 per 1 000 athletic exposures. A total of 60 injuries were reported during the 24-week training season. Sixteen of these were index and 44 were recurrent injuries. The knee was most common injury site, followed by the shoulder, elbow and lower back. Swimmers were unable to identify the cause of most injuries. There was little or no adaptation of training in response to injury, and the majority of injuries were untreated. The high injury incidence over the study period emphasises the increased injury vulnerability of this study population.

In addition, the high number of recurrent injuries, the minimal adaptation of training loads in response to injury, and the low access to appropriate treatment suggest a lack of knowledge or poor practices regarding swimming-related injuries. Future studies should investigate the coaches' and swimmers' knowledge, attitudes and practices regarding swimming-related injuries. Appropriate interventions are needed to improve health literacy, and to ensure that adolescent swimmers access appropriate care and management of injuries.

To determine if any specific intrinsic factors and extrinsic factors were associated with increased risk of injury in competitive adolescent swimmers.

Swimmers with a previous injury history were 7.5 times more likely to sustain an injury, compared to swimmers without any previous injury history. In addition, swimmers who incorporated breaststroke training for less than 20% of their individual training hours were almost 13 times more likely to sustain an injury, compared to swimmers who spent ≥ 20% of training hours in breaststroke. No other descriptive, screening or training and competition factors were associated with an increased injury risk in this study. These findings highlight the importance of developing a musculoskeletal screening tool that is appropriate for young athletes, including adolescents. It is also possible that some aspects of training might reduce the risk for injury. However, the mechanisms of any potential protective effect associated with specific swimming strokes is unclear, and further research is needed.

Based on the findings of this study, the number of injuries sustained by competitive adolescent swimmers over a six-month period is high. Improving the health literacy of swimmers, parents, and coaches could facilitate more appropriate training loads and injury management. To our knowledge, this was the first prospective study to evaluate injury patterns in adolescent competitive swimmers. Therefore, further research is needed regarding injury incidence, risk factors and training profiles of this population. Moreover, consensus regarding injury definitions and training loads in adolescent swimmers is needed to standardise reporting and to facilitate further research in this field.

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APPENDIX 1: LoE rating system

Levels of Evidence for Primary Research Question[1]

	Types of Studies			
	Therapeutic Studies—Investigating the Results of Treatment	Prognostic Studies—Investigating the Effect of a Patient Characteristic on the Outcome of Disease	Diagnostic Studies—Investigating a Diagnostic Test	Economic and Decision Analyses—Developing an Economic or Decision Model
Level I	• High-quality randomized controlled trial with statistically significant difference or no statistically significant difference but narrow confidence intervals • Systematic review[2] of Level-I randomized controlled trials (and study results were homogeneous[3])	• High-quality prospective study[4] (all patients were enrolled at the same point in their disease with ≥80% follow-up of enrolled patients) • Systematic review[2] of Level-I studies	• Testing of previously developed diagnostic criteria in series of consecutive patients (with universally applied reference "gold" standard) • Systematic review[2] of Level-I studies	• Sensible costs and alternatives; values obtained from many studies; multiway sensitivity analyses • Systematic review[2] of Level-I studies
Level II	• Lesser-quality randomized controlled trial (e.g., <80% follow-up, no blinding, or improper randomization) • Prospective[4] comparative study[5] • Systematic review[2] of Level-II studies or Level-I studies with inconsistent results	• Retrospective[6] study • Untreated controls from a randomized controlled trial • Lesser-quality prospective study (e.g., patients enrolled at different points in their disease or <80% follow-up) • Systematic review[2] of Level-II studies	• Development of diagnostic criteria on basis of consecutive patients (with universally applied reference "gold" standard) • Systematic review[2] of Level-II studies	• Sensible costs and alternatives; values obtained from limited studies; multiway sensitivity analyses • Systematic review[2] of Level-II studies
Level III	• Case-control study[7] • Retrospective[6] comparative study[5] • Systematic review[2] of Level-III studies	• Case-control study[7]	• Study of nonconsecutive patients (without consistently applied reference "gold" standard) • Systematic review[2] of Level-III studies	• Analyses based on limited alternatives and costs; poor estimates • Systematic review[2] of Level-III studies
Level IV	Case series[8]	Case series	• Case-control study • Poor reference standard	• No sensitivity analyses
Level V	Expert opinion	Expert opinion	Expert opinion	Expert opinion

1. A complete assessment of the quality of individual studies requires critical appraisal of all aspects of the study design.
2. A combination of results from two or more prior studies.
3. Studies provided consistent results.
4. Study was started before the first patient enrolled.
5. Patients treated one way (e.g., with cemented hip arthroplasty) compared with patients treated another way (e.g., with cementless hip arthroplasty) at the same institution.
6. Study was started after the first patient enrolled.
7. Patients identified for the study on the basis of their outcome (e.g., failed total hip arthroplasty), called "cases," are compared with those who did not have the outcome (e.g., had a successful total hip arthroplasty), called "controls."
8. Patients treated one way with no comparison group of patients treated another way.

This chart was adapted from material published by the Centre for Evidence-Based Medicine, Oxford, UK. For more information, please see www.cebm.net.

APPENDIX 2: INJURY REPORT AND TRAINING QUESTIONNAIRE

Swim study - week 23

1. Swim study on some of South Africa's finest teenage swimmers.

Hi swim star, thank you so much for completing the
Weekly Injury Report and Training Questionnaire**.**

You are awesome!

Your input until the end of April (25 weeks total) will hugely benefit adolescent swimmers across the world in years to come. It helps researchers determine why swimming injuries happen and how to possibly prevent them. You are the generation of the future!

Swim study - week 23

2. Introduction

*** What is your name?**

*** What week of the survey is this?**

Please see the week number on the descriptive email attached to the link

*** Do you currently have an injury?**

- Yes
- No

Swim study - week 23

3. Section A: Injury Section

*** What type of injury do you have?**

Please complete even if you reported on the injury last time and mark as ongoing injury.

- New injury
- Ongoing injury

*** What day this week did your injury happen?**

Please choose only one response.

- Monday
- Tuesday
- Wednesday
- Thursday
- Friday
- Saturday
- Sunday
- I don't know
- Not applicable

*** What time did the injury happen?**

Please choose only one response.

- am (before lunch)
- pm (after lunch)
- I don't know

Swim study - week 23

4. Section A: Injury Section

*** Where is the injury on your body?**

Please tick all that apply.

- Head
- Face
- Neck
- Middle back
- Lower back
- Shoulder
- Upper arm
- Elbow
- Forearm
- Wrist
- Hand
- Hip
- Thigh
- Knee
- Lower leg
- Ankle
- Foot
- Other (please specify)

*** Please choose the most painful injury from the list above and answer the following** -Where do you think the pain from your injury comes from?

Please choose only one response.

- Bone
- Muscle
- Joint
- Ligament
- Tendon
- Cartilage
- I don't know
- Other (please specify)

*** Please use the same injury from the previous question and rank how your pain is feeling right now (at rest position).**

Please rank your injury on a scale of 0 - 10, with 0 being the best (no pain at all) and 10 being the worst (worst pain ever).

*Please note: answering 0 means you are currently pain-free.

*** Please use the same injury from the previous question and rank how your pain is feeling while you are swimming.**

Please rank your injury on a scale of 0 - 10, with 0 being the best (no pain at all) and 10 being the worst (worst pain ever).

*Please note: answering 0 means you are currently pain-free.

Swim study - week 23

5. Section A: Injury Section

*** Please indicate when your injury happened.**

Please choose only one response.

- ○ Swimming training
- ○ Swimming Competition
- ○ Land-training
- ○ Stretching
- ○ Other sports
- ○ I don't know
- ○ Other (please specify)

Swim study - week 23

6. Section A: Injury Section

*** What stroke were you swimming when you got injured?**

Please choose only one response.

- ○ Individual Medley (IM)
- ○ Freestyle
- ○ Butterfly
- ○ Backstroke
- ○ Breaststroke
- ○ I don't know

*** What do you think caused the injury during your swim training?**

You may choose up to three options that you feel are most applicable.

- ☐ Overuse
- ☐ Wrong swimming technique
- ☐ High intensity training session
- ☐ High training volume (too much training)
- ☐ Sudden change in the amount of swim training
- ☐ Sudden change in the intensity of swim training
- ☐ Poor warm-up
- ☐ Fatigue
- ☐ Breathing to only one side
- ☐ I don't know
- ☐ Other (please specify)

Swim study - week 23

7. Section A: Injury Section

*** What do you think caused the injury during your land-training?**

You may choose up to three options that you find are most applicable.

- ☐ Overuse
- ☐ Wrong technique
- ☐ High intensity training session
- ☐ High land-training volume (too much land-training)
- ☐ Sudden change in the amount of land-training
- ☐ Sudden change in the intensity of land-training
- ☐ Poor warm-up
- ☐ Fatigue
- ☐ Heavy weights
- ☐ I don't know
- ☐ Not applicable
- ☐ Other (please specify)

Swim study - week 23

8. Section A: Injury Section

*** Please indicate the sport you were playing when you got injured.**

Please choose only one response.

- ○ Athletics
- ○ Badminton
- ○ Baseball
- ○ Basketball
- ○ Cricket
- ○ Gymnastics
- ○ Handball
- ○ Hockey
- ○ Ice-skating
- ○ Netball
- ○ Skating on the road
- ○ Soccer
- ○ Volleyball
- ○ Waterpolo
- ○ Not applicable
- ○ Other (please specify)

Swim study - week 23

9. Section A: Injury Section

*** Which of these things increase the pain from your injury while swimming?**

Please tick all that apply.

- ☐ Pull bouy
- ☐ Paddles
- ☐ Kickboards
- ☐ Ankle bands
- ☐ Swim drills
- ☐ Time trials
- ☐ Not applicable (it stays the same)

*** Which treatment did you have for your injury in the last week?**

Please tick all that apply.

- ☐ None
- ☐ GP
- ☐ Physiotherapy
- ☐ Chiropracter
- ☐ Biokinetics
- ☐ Orthopaedic surgeon
- ☐ Massage
- ☐ Ice
- ☐ Rest
- ☐ Injections
- ☐ Acupuncture / dry needling
- ☐ Other
- ☐ Medication (please specify)

If your answer to the above question was 'other', please specify.

* How many swim sessions did you have to <u>MISS</u> this week because of your injury?

- ◌ 0
- ◌ 1
- ◌ 2
- ◌ 3
- ◌ 4
- ◌ 5
- ◌ 6
- ◌ 7
- ◌ 8
- ◌ 9
- ◌ 10
- ◌ 11
- ◌ 12

* How many swim sessions had to be CHANGED because of your injury?

'Changed' means that you could not complete the training set given to you by your coach because of the pain. It mean you had to change the set or even had to substitute it with an extra land-session instead.

- ◌ 0
- ◌ 1
- ◌ 2
- ◌ 3
- ◌ 4
- ◌ 5
- ◌ 6
- ◌ 7
- ◌ 8
- ◌ 9
- ◌ 10
- ◌ 11
- ◌ 12

Swim study - week 23

10. Section B: Training Exposure Section

*** On how many <u>days</u> did you have swim training this week?**

Please choose only one response.

- 0
- 1
- 2
- 3
- 4
- 5
- 6
- 7

*** How many swim training <u>sessions</u> did you have in <u>total</u> this week?**

Please count morning and afternoon training as separate sessions and choose only one response.

- 0
- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- 11
- 12

*** How long was the average duration of one swim training session in hours?**

Please choose only one response.

- 0 - 1
- 1 - 2
- 2 - 2½
- 2½ - 3
- 3 - 3½
- 3½ - 4
- > 4

*** What was the total duration of swim training sessions this week inhours?**

Please choose the most correct one.

- 0
- 0 - 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10
- 10 - 12
- 12 - 14
- 14 - 16
- 16 - 18
- 18 - 20
- > 20

*** What was the <u>average distance</u> covered in one swim session in <u>kilometres</u> this week?**

Please choose the most correct one.

- 0 - 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- > 10

Swim study - week 23

11. Section B: Training Exposure Section

*** Please choose a number that <u>best describes</u> how difficult the <u>intensity</u> your swim training sessions this past week were on average?**

If there is no description next to the number it means it is somewhere inbetween the number above and below it.

- 0 = Rest
- 1 = Really easy
- 2 = Easy
- 3 = Moderate
- 4 = Sort of hard
- 5 = Hard
- 6
- 7 = Really hard
- 8
- 9 = Really, really hard
- 10 = Maximal, just like your hardest race ever

*** How many swim competitions did you have this week?**

The question refers to competitions as a whole, not the individual races swum at these competitions.

- 0
- 1
- 2
- 3
- > 3

*** How many sessions of land-training did you have last week?**

Please choose only one response.

- 0
- 1
- 2
- 3
- 4
- 5
- 6
- 7

Swim study - week 23

12. Section B: Training Exposure Section

*** How long was the <u>average</u> duration of one land-training session this week in<u>hours</u>?**

Please choose the most appropriate response.

- 0 - 30 minutes
- 30 - 60 minutes
- 1 - 1½ hours
- 1½ - 2 hours
- > 2 hours

*** What exercise did you do in your dry-land training this week?**

Please tick all that apply.

- ☐ Cycling
- ☐ Running
- ☐ Weights (machines and free weights)
- ☐ Body weight (squats, push-up's, planks etc.)
- ☐ Stretch cords
- ☐ Rowing
- ☐ Other (please specify)

Swim study - week 23

13. Section B: Training Exposure Section

*** Which other sport did you participate in this week?**

Please tick all that apply.

- ☐ Athletics
- ☐ Badminton
- ☐ Baseball
- ☐ Basketball
- ☐ Cricket
- ☐ Gymnastics
- ☐ Handball
- ☐ Hockey
- ☐ Ice-skating
- ☐ Netball
- ☐ Rugby
- ☐ Skating on the road
- ☐ Soccer
- ☐ Volleyball
- ☐ Waterpolo
- ☐ Not applicable
- ☐ Other (please specify)

Swim study - week 23

14.

Thanks for taking the time to complete the Weekly Questionnaire. Please click the submit button below to upload the information to me.

APPENDIX 3: Beighton score

Test	Criteria	Right	Left
Fifth finger extension test	Passive extension> 90 °	1	1
	Passive extension ≤ 90 °	0	0
Wrist flexion thumb abduction test	Passively abduct the thumb to oppose the flexor aspect of the forearm	1	1
	Unable to passively abduct the thumb to oppose the flexor aspect of the forearm	0	0
Elbow extension test	Hyperextension > 10 °	1	1
	Hyperextension ≤ 10 °	0	0
Trunk and hip flexion test	Knees fully extended, forward flexion of the trunk, able to place the flat of the hand on the floor	1	
	Knees fully extended, forward flexion of the trunk, unable to place the flat of the hand on the floor	0	
Knee extension test	Hyperextension > 10 °	1	1
	Hyperextension ≤ 10 °	0	0
Total		**9**	

APPENDIX 4: TABLES COMPARING STUDIES FOR MEASUREMENT INSTRUMENTS

Table A: Summary of studies investigating the Beighton Score

	Study objective	Participants	Cut-off for GJH	Results	Conclusions
Boyle et al.[119]	**To determine intrarater and interrater reliability of the following:** 1) Composite BHJMI scores (i.e. overall score from 0 – 9); 2) BHJMI scores in 3 categories, (i.e. 0 - 2, 3 - 4, and 5 – 9)	42 Female volunteers from academic physical therapy department & high- school Intrarater reliability: All 42 volunteers 36 tested for Interrater reliability: 36 of the 42 volunteers	Scores ≥ 5 positive tests out of 9 indicative of GJH	The percentage agreement & Spearman rho for reliability of BHJMI composite scores: 69% and 0.86 intrarater 51% and 0.87 interrater The percentage agreement and the Spearman rho for reliability of category scores: 81% and 0.81 intrarater 89% and 0.75 interrater	The BHJMI is quick, taking 1 minute or less to complete, and does not require any special equipment. Reliability of the BHJMI was good to excellent in screening for GJH in females aged 15 – 45 y.
Cameron et al.[123]	To determine relationship among sex, joint hypermobility and GHJ instability within a young physically active cohort. To describe GJH within this population	714 Freshman Class United States Military Academy 630 males 84 females	≥ 2 positive tests out of 9 indicative of GJH (corresponding to 95% used)	Most participants (78%) showed no signs of GJH. 11 participants (1.5%) had BS ≥ 4 When race and gender were controlled, those with BS ≥ 2 were 2.5 times more likely to report history of GHJ instability (odds ratio = 2.48. 95% CI=1.19, 5.20, p = 0.016) Females scored higher than men (p = 0.658) but not related to GHJ instability when other variables were controlled	GJH and GHJ instability are related (p = 0.023) regardless of gender or race

Key: &– and; BHJMI- Beighton and Horan Joint Mobility Index; GJH- Generalised joint hypermobility; Y- year; GHJ- Glenohumeral joint; CI- confidence interval; ROM- range of movement; BJHS- benign joint hypermobility syndrome; VAS- visual analogue scale; H- hours; MSK: musculoskeletal; BS- Beighton score; ADL- Activity of daily living.

	Study objective	Participants	Cut-off for GJH	Results	Conclusions
Jansson et al.[103]	To evaluate differences between competitive swimmers and age- and gender-matched school children regarding GJH, GHJ laxity and shoulder ROM	1,397 participants 120 competitive swimmers aged 9 and 12 y 53 males 67 females 1,277 reference group: 120 age- and gender-matched school children	Not mentioned	Male swimmers showed a higher degree of GJH at 9 y ($p = 0.013$) and 12 y ($p=0.003$) compared to reference group Female swimmers showed a lower degree of GJH compared with references at 9 y ($p = 0.021$); no significant difference was found at 12 y Male and female swimmers had decreased shoulder internal rotation Female swimmers (9 and 12 y) had decreased external rotation compared to controls. Male swimmers (12 y) showed decreased external rotation	Competitive swimming in children results in decreased shoulder rotation ROM; the reason is still unclear and needs further investigation
Juul-Christensen et al.[120]	Three phase study to test the reproducibility of tests and criteria for GJH and BJHS	74 total patients Patients in each phase: Phase 1: 14 Phase 2: 20 Phase 3: 40	Scores ≥ 5 positive tests out of 9 indicative of GJH	Overall agreement in phase 2 showed kappa values of: 0.95 for GJH, 0.90 for BJHS Reproducibility for diagnosing GJH and BJHS in phase 3 showed kappa values of: 0.74 for GJH, 0.84 for BJHS Kappa > 0.80 in the Beighton tests for diagnosing GJH (except for the fifth fingers and elbows [0.60]) Kappa > 0.73 in the Brighton tests for diagnosing BJHS (except for the skin signs [0.63]) Lowest kappa (0.57) was found in the Rotès-Quérol tests (except for the right shoulder [0.31])	Good to excellent reproducibility of tests and criteria for GJH and BJHS with kappa scores from Beighton tests and Brighton Criteria for BJHS Future research on the validity of the tests and criteria for joint hypermobility is urgently needed

Key: &– and; BHJMI- Beighton and Horan Joint Mobility Index; GJH- Generalised joint hypermobility; Y- year; GHJ- Glenohumeral joint; CI- confidence interval; ROM- range of movement; BJHS- benign joint hypermobility syndrome; VAS- visual analogue scale; H- hours; MSK: musculoskeletal; BS- Beighton score; ADL- Activity of daily living.

	Study objective	Participants	Cut-off for GJH	Results	Conclusions
Kim et al.[101]	To evaluate spinal intervertebral mobility in patients with GJH and matched controls without GJH To investigate the influence of GJH on back pain, disability and general health status in young males	64 young males (20 - 25 y) 32 with GJH 32 without GJH	Scores ≥ 4 positive tests out of 9 indicative of GJH	GJH group showed increased ROM and intervertebral disc height compared to control group GJH increased VAS for back pain (the VAS for back pain between 2 groups was statistically different P < 0.001)	Young males with GJH had excessive lumbar segmental motion associated with low back pain, disability and limited physical activity
Konopinski et al.[124]	To compare injury incidence between non- and hypermobile elite male soccer players	54 English premier-league soccer players	Scores ≥ 4 positive tests out of 9 indicative of GJH	133 total injuries sustained during 13897.5 h of exposure Hypermobile players: Higher incidence (95% CI) and mean difference 15.65 injuries / 1000 h. Hence, they are more likely to experience at least one injury, re-injury or more severe injury There were 49 moderate injuries There were 9 severe knee injuries but not career ending (6 involving cartilage)	GJH related to increased injury incidence resulting in more days absent from training and match play Recommended implementation of screening for GJH in elite soccer players

Key: &– and; BHJMI- Beighton and Horan Joint Mobility Index; GJH- Generalised joint hypermobility; Y- year; GHJ- Glenohumeral joint; CI- confidence interval; ROM- range of movement; BJHS- benign joint hypermobility syndrome; VAS- visual analogue scale; H- hours; MSK: musculoskeletal; BS- Beighton score; ADL- Activity of daily living.

	Study objective	Participants	Cut-off for GJH	Results	Conclusions
Leone et al.[126]	To determine if GJH is associated with MSK pain in school-children	1,046 Italian school-children (7 - 15 y)	Scores ≥ 5 positive tests out of 9 indicative of GJH	18% prevalence of MSK pain reported by participants 22% of participants with MSK pain had GJH Functional limitations measured by a '*disability score*' correlated in a weak negative way with BS ($p = 0.03$) The *'physical activity score'* correlated in a weak positive way with BS ($p = 0.012$)	No association between hypermobility and MSK pain Hypermobile children did not experience functional limitations in ADL & were more active than non-hypermobile children
Smits-Engelsman et al.[109]	To evaluate the validity of the BS as a generalised measure of hypermobility To measure the presence of hypermobility and pain in a population of school-children	551 Dutch elementary school-children (6 - 12 y) 258 males 293 females	Increased mobility: 5-6 positive tests out of 9 Hypermobile ≥ 7 positive tests out of 9	More than 35 % scored ≥ 5/9 on BS Higher BS corresponded with increased ROM of other joints measured No significant gender differences	BS is a valid instrument to measure GJH in children aged 6 - 12 y Goniometry must be used to measure No additional items are needed to improve the scale It is recommended that cut-off of ≥ 7/9 GJH should be considered in future

Key: &– and; BHJMI- Beighton and Horan Joint Mobility Index; GJH- Generalised joint hypermobility; Y- year; GHJ- Glenohumeral joint; CI- confidence interval; ROM- range of movement; BJHS- benign joint hypermobility syndrome; VAS- visual analogue scale; H- hours; MSK: musculoskeletal; BS- Beighton score; ADL- Activity of daily living.

	Study objective	Participants	Cut-off for GJH	Results	Conclusions
Smith et al.[102]	To evaluate the incidence of hypermobility in young female netball players To determine the relation between hypermobility, previous injuries sustained in netball or other sports, and the use of protective equipment	200 Female netball players (6 - 16 y)	Scores ≥ 5 positive tests out of 9 indicative of GJH	69 players sustained some injury while playing netball Players with BS of ≥ 5 / 9 are 3 times more likely to be injured. Injuries sustained according to BS categories: 21% in category 0 - 2 37% in category 3 – 4 43% in category 5 – 9 These differences were significant ($p < 0.025$) Injuries most common in the ankle (42%), knee (27%), and fingers (15%)	Hypermobility is significantly associated with increased prevalence of injuries in junior netball players A targeted interventional approach may help to reduce injuries in this susceptible group

Key: &– and; BHJMI- Beighton and Horan Joint Mobility Index; GJH- Generalised joint hypermobility; Y- year; GHJ- Glenohumeral joint; CI- confidence interval; ROM- range of movement; BJHS- benign joint hypermobility syndrome; VAS- visual analogue scale; H- hours; MSK: musculoskeletal; BS- Beighton score; ADL- Activity of daily living.

Table B: Summary of studies using hand-held dynamometery

Article	Objective	Participants	Measures and muscle groups	Results	Conclusion
Cadogan et al.[111]	To establish intraexaminer & interexaminer reliability of shoulder ROM measures & muscle force using a HHD with the ability to standardize overpressure force during passive ROM tests	40 patients with shoulder pain	Shoulder strength using HHD: Active ROM: Flexion Passive ROM: Abduction External rotation Resisted ROM: Abduction External rotation	All tests show high levels of intraexaminer reliability (ICC 085 - 099; LOA 6 - 24° & 11 - 70 kg) Highest levels of interexaminer reliability observed for flexion measures (ICC 088 - 095; LOA 14 - 22°) Passive ROM tests demonstrated 'moderate - substantial' interexaminer reliability (ICC 045 -062; LOA 25 - 34°) Resisted tests ICCs ranged from 068 - 084, and LOA from 32 – 85 kg	All tests demonstrated high levels of intraexaminer reliability Flexion measures showed high levels of inter- and intrarater reliability Measures of peak isometric force (resisted abduction and external rotation) & passive ROM to standardize overpressure force also demonstrated clinically acceptable levels of intraexaminer reliability
Hayes et al.[128]	To determine the interrater & intrarater reliability of 3 tests MMT, HHD, spring-scale dynamometer) for assessing isometric shoulder muscle strength	17 Patients with shoulder complaints Interrater group: 8 volunteers 3 male, 5 female (age 57 - 72 y) Intrarater group: 9 volunteers 5 male, 4 female (age 29 - 74 y)	MMT and HHD evaluation of strength: Flexion, external- and internal rotation, hand behind back lift-off Spring-scale dynamometer strength: Elevation, external- and internal rotation, adduction	HHD measures demonstrated excellent reliability for the interrater trial (ρ = 079 - 092) Excellent reliability for elevation, external- and internal rotation for the intrarater trial (ρ = 079 - 096) For the interrater trial, measurement of the lift-off maneuver with the HHD was significantly more reliable than with manual muscle tests (P = 002)	The HHD was the most reliable and discriminatory means for assessing strength of the rotator cuff in symptomatic subjects

Key: &- and; ROM- range of motion; HHD- hand-held dynamometer; ICC- intraclass correlation coefficient; LOA- limits of agreement; °- degree; kg- kilogram; DM1- ; MMT- manual muscle testing; IR- internal rotation; ER- external rotation; SSD- ; IST- infraspinatus strength test; ISRT- infraspinatus scapular retraction test; ROM- range of motion; SEM- standard error of measurement; MDC- minimal detectable change.

Article	Objective	Participants	Measures and muscle groups	Results	Conclusion
Hébert et al.[175]	To characterize the maximal strength of ankle eversion and dorsiflexion in DM1 patients MMT & HHD muscle testing were also compared	64 participants 46 patients with DM1 from Quebec / Lyon 22 male, 24 female 16 matched controls	MMT and HHD: Ankle: Dorsiflexion & eversion strength	HHD excellent torque measures: Eversion ($R2 = 0,94$/Quebec; 0,89/Lyon) Dorsiflexion ($R2 = 0,96$/Quebec; 0,90/Lyon) Differences between 3 groups (mild, moderate, severe DM1) & between groups & controls were all statistically significant ($p < 0,001$) No statistical differences between sites were observed ($p > 005$) MMT was unable to discriminate between 3 DM1 groups	The HHD protocol is suitable for multicentre therapeutic trials Quantitative testing accurately discriminates between healthy & DM1 patients This study is a preliminary step for the implementation of a valid, reliable & responsive clinical outcome for the measurement of muscle impairments in this population
Ramsi et al.[98]	To examine isometric shoulder IR & ER strength in high-school swimmers over a 12-week competitive season	27 high school competitive swimmers (13 male, 14 female)	HHD shoulder strength: Internal- and external rotation strength	Significant increases in internal rotation strength in both groups External rotation strength significantly improved in both males and females from preseason to midseason & from preseason to postseason IR/ER ratio revealed a significant increase from preseason to postseason	Increases in internal rotation strength without equal gains in external rotation strength This could contribute to future shoulder pathologies in competitive swimmers

Key: &- and; ROM- range of motion; HHD- hand-held dynamometer; ICC- intraclass correlation coefficient; LOA- limits of agreement; °- degree; kg- kilogram; DM1- ; MMT- manual muscle testing; IR- internal rotation; ER- external rotation; SSD- ; IST- infraspinatus strength test; ISRT- infraspinatus scapular retraction test; ROM- range of motion; SEM- standard error of measurement; MDC- minimal detectable change.

Article	Objective	Participants	Measures and muscle groups	Results	Conclusion
Roy et al.[140]	To investigate the concurrent validity of shoulder isometric strength scores using a HHD vs stationary dynamometer	38 participants (age 19 - 67 y)	Shoulder assessed with HHD and stationary dynamometer: Flexion Abduction External rotation	Men stronger than women in all tests using both instruments ($p < 0001$) Correlations between dynamometers were high in all 3 shoulder tests (good concurrent validity) : Pearson product correlation coefficients r = 081 - 093, 95% CI 066 - 092 All correlations significant ($p < 0001$) No significant differences when separated by gender or tester	Both instruments provide similar & valid assessment of shoulder isometric strength
Kollock et al.[136]	To assess intrarater, interrater, intrasession, & intersession reliability of a portable fixed dynamometer in measuring hip & knee strength	37 participants Phase 1: college graduates 2 male, 9 female Phase 2: 26 college undergraduates 7 male, 19 female	Fixed portable HHD: Knee: Flexion, extension Hip: Flexion, extension, abduction, adduction, internal- and external rotation	Phase 1 Intrasession reliability ICC (intraclass correlation coefficients): session 1: 088 - 099 session 2: 085 to 099 session3: 092 to 096 Intersession reliability ICC: range = 043 - 076 Phase 2 Intrarater reliability ICC: range = 070 - 094 Interrater reliability ICC: range = 069 - 091)	The portable fixed dynamometer showed good to high intra- and intersession reliability values for hip and knee strength Intrarater and interrater reliability were fair to high (except for hip internal rotation which showed poor reliability)

Key: &- and; ROM- range of motion; HHD- hand-held dynamometer; ICC- intraclass correlation coefficient; LOA- limits of agreement; °- degree; kg- kilogram; DM1- ; MMT- manual muscle testing; IR- internal rotation; ER- external rotation; SSD- ; IST- infraspinatus strength test; ISRT- infraspinatus scapular retraction test; ROM- range of motion; SEM- standard error of measurement; MDC- minimal detectable change.

Article	Objective	Participants	Measures and muscle groups	Results	Conclusion
Koblauer et al.[137]	To determine the inter- and intrarater reliability of HHD in measuring isometric knee strength in patients awaiting TKA	33 participants awaiting TKA 6 male, 26 female 36 interrater study 14 of these volunteered for intrarater reliability testing	HHD Knee: Flexion , extension	Inter- and intrarater reliability: Flexion: good; ICC range = 076 - 094 Extension: excellent; ICC range = 092 - 097 Measurement error was high: smallest detectable difference SDD: SDD interrater reliability ranges between 217% and 362%; SDD intrarater reliability ranges between 190% and 575% Measurement error higher for knee flexors than extensors	Modified HHD is a reliable strength measure, producing good to excellent ICC values for both inter- and intrarater reliability in this population Modified HHD is appropriate to evaluate knee strength changes in TKA patient groups, but it is not suitable to measure individual strength changes High SEM and SDD values indicate high measurement error for individual measures The use of modified HHD is not advised for use in a clinical setting
Merolla et al.[99]	To analyse the inter- and intraobserver realibility of the IST and ISRT before & after 6-months of scapular musculature rehabilitation	29 overhead athletes with scapula dyskinesis	HHD: IST, ISRT Goniometer: internal rotation changes	ICC close to 1 at baseline and 6 months indicate high inter- and intraexaminer reliability IST force values increased at 6 months for both examiners (P < 001) The mean difference between IST and ISRT values were not significant at 6 months (P > 001) Increased glenohumeral internal rotation was significant at 6 months (P < 001)	ISRT in an excellent test to assess infraspinatus weaknesses due to good realibility & easy reproducibility

Key: &- and; ROM- range of motion; HHD- hand-held dynamometer; ICC- intraclass correlation coefficient; LOA- limits of agreement; °- degree; kg- kilogram; DM1- ; MMT- manual muscle testing; IR- internal rotation; ER- external rotation; SSD- ; IST- infraspinatus strength test; ISRT- infraspinatus scapular retraction test; ROM- range of motion; SEM- standard error of measurement; MDC- minimal detectable change.

Article	Objective	Participants	Measures and muscle groups	Results	Conclusion
Whiteley et al.[132]	To describe inter-rater reliability & correlations between isometric & eccentric knee extension and flexion using HHD and isokinetic testing	216 male professional soccer players	HHD & biodex isokinetic dynamometer: Knee flexion & extension	Excellent inter-rater reliability ICC: eccentric hamstrings = 090 isometric hamstrings = 091 isometric quadriceps = 096, Medium to high correlations (r = 0322 – 0617) & all significant (p < 0001) for the comparisons between HHD & isokinetic measures	3 novel & reliable methods of examining knee flexion & extension strength using HHD requiring less examiner skill & strength than previous measures HHD examinations took less than 4 min per player to conduct & may be useful in clinical practice where isokinetic examination is difficult to implement
Janssen and Le-Ngoc[141]	To assess the reliability of a new HHD in performing concentric measurements & to determine agreement with the criterion standard isokinetic dynamometer	3 profiles of a mechanical arm	HHD and stationary isokinetic dynamometer: Elbow: Peak torque & flexion ROM	Intratester ICC reliabilities of peak torque & start-and end-ROM are excellent for both HHD and isokinetic dynamometer The angle of peak torque is fair to good in intrareliability for both devices Validity, measured within the limits of agreement (LOA) between the 2 devices, was clinically acceptable for peak torque and start ROM	HHD can be used to obtain dynamic measurements of joint motion HHD Intratester reliability is excellent and in clinical acceptable agreement with the isokinetic dynamometer for peak torque and start ROM End ROM was not in agreement due to systematic error in the isokinetic dynamometer measurement for 1 of the 3 profiles Intratester reliabilities of the angle of peak torque were fair to good for both the HHD and isokinetic dynamometer, but the LOA were not clinically acceptable

Key: &- and; ROM- range of motion; HHD- hand-held dynamometer; ICC- intraclass correlation coefficient; LOA- limits of agreement; °- degree; kg- kilogram; DM1- ; MMT- manual muscle testing; IR- internal rotation; ER- external rotation; SSD- ; IST- infraspinatus strength test; ISRT- infraspinatus scapular retraction test; ROM- range of motion; SEM- standard error of measurement; MDC- minimal detectable change.

Article	Objective	Participants	Measures and muscle groups	Results	Conclusion
Stark et al.[127]	To examine current evidence regarding the reliability & validity of HHD for assessment of muscle strength in the clinical setting	17 manuscripts selected for review	HHD vs gold standard isokinetic testing: Shoulder, elbow, knee, hip, ankle	Evaluated studies showed minimal difference between HHD and isokinetic test results	HHDs are to use, portable, inexpensive, small compared with isokinetic devices HHD can be regarded as a reliable & valid instrument for muscle strength assessment in a clinical setting
Thorborg et al.[110]	To examine the inter-tester reliability of strength assessments of isometric hip abduction, adduction, flexion, extension and knee-flexion strength, using HHD with external belt-fixation	21 healthy athletes 15 male, 6 female	HHD with external belt fixation: Hip: Flexion, extension, abduction, adduction Knee: Flexion	No systematic interrater differences were observed for hip or knee actions ICC ranged from 076 - 095 SEM % ranged from 5 - 11 %, and MDC % from 14 - 29 % for different hip & knee actions	Isometric hip- and knee-strength measurements have acceptable inter-tester reliability using HHD with belt-fixation The procedure is perfectly suited for the evaluation and monitoring of strong athletes with hip, groin and hamstring injuries
Tate et al.[42]	To determine whether physical characteristics, exposure, or training variables differ between swimmers with & without shoulder pain or disability	234 competitive swimmers All female (8 - 77 y) grouped by age for comparison	Shoulder isometric strength measured with HHD: Internal- and external rotation, abduction, flexion	Normalised internal rotation torque was less in the 12 - 14 y group Middle trapezius weakness present more in the 8 - 11 y age group Weakness of the middle trapezius & shoulder internal rotators was seen in younger swimmers	Strengthening of the middle trapezius and internal rotators should be a component of a swimmer's programme to prevent shoulder injury Swimmers < 12 y experienced substantial shoulder pain Older swimmers experienced pain, dissatisfaction and disability High-school swimmers were the most symptomatic & incurred the greatest shoulder load

Key: &- and; ROM- range of motion; HHD- hand-held dynamometer; ICC- intraclass correlation coefficient; LOA- limits of agreement; °- degree; kg- kilogram; DM1- ; MMT- manual muscle testing; IR- internal rotation; ER- external rotation; SSD- ; IST- infraspinatus strength test; ISRT- infraspinatus scapular retraction test; ROM- range of motion; SEM- standard error of measurement; MDC- minimal detectable change.

Article	Objective	Participants	Measures and muscle groups	Results	Conclusion
Tate et al.[42]	To determine whether physical characteristics, exposure, or training variables differ between swimmers with & without shoulder pain or disability	234 competitive swimmers All female (8 - 77 y) grouped by age for comparison	Shoulder isometric strength measured with HHD: Internal- and external rotation, abduction, flexion	Normalised internal rotation torque was less in the 12 - 14 y group Middle trapezius weakness present more in the 8 - 11 y age group Weakness of the middle trapezius & shoulder internal rotators was seen in younger swimmers	Strengthening of the middle trapezius and internal rotators should be a component of a swimmer's programme to prevent shoulder injury Swimmers < 12 y experienced substantial shoulder pain Older swimmers experienced pain, dissatisfaction and disability High-school swimmers were the most symptomatic & incurred the greatest shoulder load
Nodehi-Moghadam et al.[100]	The purpose of this study was to compare shoulder rotational strength, ROM and proprioception between the throwing athletes and non-athletic persons	30 participants 15 throwing athletes 15 non-athletes	Shoulder ROM tested with HHD: Internal- and external rotation	No significant difference in internal rotation ROM between groups (p = 03) External rotation ROM was significantly more in athletic subjects (P = 003) Athletes had significantly higher isometric strength of shoulder rotation than the nonathletic group (p < 005) Comparison of the rotation strength of dominant side in each group showed athletes had significant lower isometric strength of external rotation than internal rotation (p < 0001) Throwing athletes had higher joint position acuity (p = 001)	The repetitive nature of overhead throwing and the high forces that it causes result in adaptive changes of the dominant extremity Throwing can lead to mobility, strength and neural adaptation

Key: &- and; ROM- range of motion; HHD- hand-held dynamometer; ICC- intraclass correlation coefficient; LOA- limits of agreement; °- degree; kg- kilogram; DM1- ; MMT- manual muscle testing; IR- internal rotation; ER- external rotation; SSD- ; IST- infraspinatus strength test; ISRT- infraspinatus scapular retraction test; ROM- range of motion; SEM- standard error of measurement; MDC- minimal detectable change.

Table C: Summary of studies investigating shoulder rotation measurements and deficits (glenohumeral internal rotation deficit)

Article	Objective	Participants	Measures	Data collection period	Results	Conclusion
Riemann et al.[14]	To examine shoulder ER, isolated IR, composite IR, & TAM ROM by hand dominance, sex & age group	144 competitive swimmers (age 12 - 61 y)	Demographics questionnaire; Goniometer to measure shoulder ROM: ER IIR CIR TAM	4 months	ER: significantly greater ($p < 00063$) dominant in most of the population Significantly greater in non-dominant in youth men compared to high school IIR: significantly greater in the non-dominant arm regardless of sex or age (446 ± 718, 95% CI = 434 – 458°) than in the dominant arm (412 ± 748, 95% CI = 400 – 424°) CIR: non-dominant shoulder (609 ± 98°, 95% CI= 592 – 625°) greater than dominant shoulder (551 ± 94°, 95% CI = 536 – 567°) Men (563 ± 92°, 95% CI = 548 – 578°) displayed less CIR than women (597 ± 105°, 95% CI = 580 – 615°) TAM: The dominant shoulder (1463 ± 113° 95% CI = 1444 – 1481°) had less than the non-dominant shoulder (1479 ± 125°, 95% CI = 1458 – 1499°)	Differences in ROM between dominant and non-dominant side Dominant shoulder: significantly greater ER ROM Non-dominant shoulder: significantly greater IIR, composite IR and TAM ROM Further research needs to examine altered ROM and injury risk

Key: ER- external rotation; IR- internal rotation; CIR- composite internal rotation (glenohumeral rotation plus scapulothoracic protraction); &- and; TAM- ER plus composite IR; ROM- range of motion; IIR- isolated internal rotation; CI- confidence interval; TAMD- total arc of motion deficit; °- degree; GIRD- glenohumeral internal rotation deficit.

Article	Objective	Participants	Measures	Data collection period	Results	Conclusion
Torres and Gomes[16]	To measure & compare glenohumeral IR ROM in asymptomatic tennis players & swimmers	54 volunteers 3 groups: tennis players swimmer control group	Goniometer: IR; ER; TAM GIRD TAMD	7 months	Mean GIRD: Tennis players: 239° ± 84° ($p < 0001$) Swimmers: 12° ± 68° ($p < 0001$) Control group: 49° ± 74° ($p = 0035$) Dominant shoulders showed significant difference between all groups Between tennis players & swimmers, the difference in IR of the dominant shoulder was 97° ($p = 0002$)	Dominant limbs had less IR than non-dominant limbs in all groups The IR deficit in tennis players was double the deficit found for swimmers Mean difference between limbs in the control group was less than 5° (ie within normal limits)
Myers et al.[112]	To identify increased posterior shoulder tightness & GIRD without increased external rotation gain in throwers diagnosed with pathologic internal impingement	22 total participants (age 18 - 30 y) 11 competitive baseball players with pathologic impingement 11 controls with no injury	MRI arthrogram; Orthopaedic assessment; Goniometer: IR; ER; TAM GIRD ER gain Posterior shoulder tightness	Once-off	GIRD measurement: Baseballers = –197 controls = –111° Difference in posterior shoulder tightness: Baseballers = –42 cm controls = –09 cm ER gain: no significant differences between groups	Throwing athletes had significantly greater GIRD's & posterior shoulder tightness compared to control subjects Findings indicate tightening of posterior capsule/ rotator cuff that add to impingement Management should include posterior shoulder stretching

Key: ER- external rotation; IR- internal rotation; CIR- composite internal rotation (glenohumeral rotation plus scapulothoracic protraction); &- and; TAM- ER plus composite IR; ROM- range of motion; IIR- isolated internal rotation; CI- confidence interval; TAMD- total arc of motion deficit; °- degree; GIRD- glenohumeral internal rotation deficit.

Article	Objective	Participants	Measures	Data collection period	Results	Conclusion
Kibler et al.[144]	To determine: 1) how much rotational change occurs after a single throwing episode; 2) if these changes return to baseline by the next throwing episode; 3) whether pitching role affects the amount of change that occurs	45 professional baseball players	Goniometer: GIR GER TAM	3 days	All participants GIR measures (mean 19°) were greater at baseline that follow-up (range 12 - 14°) ($p < 0001$) Values of GIR did not return to baseline in study duration GER and TAM increased from baseline measures	GIR most affected over 4-day cycle after acute throwing episode -GIR less than baseline 72 hours later GIR changes should be expected after an acute throwing episode: conditioning & recovery programmes should be used to modify the changes GIR is dynamic: studies should state when during pitching cycle measurement was obtained
Ellenbecker et al.[134]	To measure GIR & GER in unilaterally dominant upper extremity athletes to compare TAM between dominant & non-dominant sides	163 elite athletes 117 tennis players 46 baseball players	Goniometer: GIR GER TAM	Once-off	Baseball players: No significant difference ($p > 005$) in TAM between extremities (1457° vs 1469°) Tennis players: significantly less ($p < 0001$) dominant arm TAM (1491° vs 1582°)	Rotational patterning in unilaterally dominant overhead athletes is important for injury prevention, rehabilitation and improving performance

Key: ER- external rotation; IR- internal rotation; CIR- composite internal rotation (glenohumeral rotation plus scapulothoracic protraction); &- and; TAM- ER plus composite IR; ROM- range of motion; IIR- isolated internal rotation; CI- confidence interval; TAMD- total arc of motion deficit; °- degree; GIRD- glenohumeral internal rotation deficit.

APPENDIX 5: Information sheet and assent form for participants < 18 years

UNIVERSITY OF CAPE TOWN

Faculty of Health Sciences

Department of Health and Rehabilitation Sciences

Divisions of Communication Sciences and Disorders; Nursing and Midwifery; Occupational Therapy; Physiotherapy; Disability Studies

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Observatory, Cape Town, W Cape, 7925
Tel: +27 (0) 21 406 6401/ 6428/ 6628/ 6534
Fax: +27 (0) 21 406 6323

The epidemiology of injuries in competitive swimming adolescents attending a Johannesburg swim squad

Dear Swimmer,

My name is Inneke Scorgie and I am doing my Masters in Physiotherapy at the University of Cape Town. You are invited to take part in a study I am doing. My study will be testing what injuries young swimmers get during six months of swimming training. The testing helps us to figure out why we get pain and injuries.

If you decide to take part in my study, you need to know the following:

- The study will be done from October 2014 until the end of April 2015.
- **You need to be between the age of 12 and 18 to take part.**
- We will arrange an information evening before we start the study where you or your parents can ask questions. I will explain the procedure properly then so that you can understand it.
- In the beginning I will do some easy tests with you in the gym. I will have some physiotherapy students helping me as well to make the process easier and quicker. Before testing you will do a warm-up with your coach. I will explain the process properly, show you pictures and give you a demonstration of what I want you to do. If you are still not sure you can ask questions at any time. It is not the type of test you can prepare for. The testing will take about one hour during your swim time.

- We will do the following for the tests:
    - Ask you some questions about your swimming and injury history.
    - Take some measurements of your height, weight and joint movements.

- Measure your shoulder and knee muscle strength using a little machine.
- Measure your shoulder movement.
- Measure your joint movement.

- I will also write down your time for the 100 meter freestyle time trial that you will do with your coach in October 2014, in January and in April 2015.

Now this is where your important role comes in:

- I will need you to keep a swimming diary (similar to your homework diary) on the internet or on your cell phone if you have a Smart Phone (like an I-phone or Samsung galaxy). I will invite you over email, facebook or weblink to sign-up with your swimming diary. You will log-in once a week with your own password and follow the step by step instructions. It should not take you longer than 10 minutes to fill in. In this diary I will ask questions about the following: (I will explain all of this in much more detail later)
    1. How far and how long did you swim this week including all competitions?
    2. How difficult were the training sessions this week?
    3. Did you get an injury this week? If the answer is yes, then you need to complete the rest:
        4. Where is the injury?
        5. Did the injury stop you from swimming?
        6. Did you do any other sport this week and if yes, what was it?
        7. Did you have treatment?

- I will need you to send this information to me **EVERY** week. You can choose any day of the week but it might be easiest to write on a Sunday after the weeks training is finished. You will need to do this from October until April.
- If you forget to send it to me by mistake, don't panic – I will send an SMS reminder or phone you to get the information. You will also get a reminder each week over the internet.

If you agree to take part in this study it is of your own free will and you have the right to stop at any time if you no longer want to continue. You will not be getting any treatment from this study because it is only meant to collect information. Unfortunately you will also not be paid for taking part.

Privacy and confidentiality

All of the information we get from you will remain confidential meaning it will only be shared with yourselves and your parents. You can then choose if you want to tell your coach the information. The information will be kept safe on computer with a password to protect it. If the study gets published I will not be using your name meaning you will stay anonymous.

Anticipated benefits

By doing tests we can see if there are any weaknesses or differences in your left compared to your right side. This information could help with correcting your stroke. Other than this, there is no direct benefit to you in taking part in this study. The results of this study may help our understanding of injuries in adolescents and may assist in the development of future injury prevention strategies.

Possible risks

Some of the tests we do are physical strength tests so you may experience some muscle stiffness afterwards. This is not dangerous and will be reduced by making sure you warm-up properly beforehand with your coach. Each test will be properly explained until you understand what is needed. You will also be shown a demonstration and pictures. You are allowed to ask questions during testing if you are not sure of the procedure. There are no risks with completing the online injury report form the injury questionnaire.

What if something goes wrong?

The University of Cape Town has insurance to cover any study-related injury. Your parents/legal guardians have been given more detailed information about this insurance policy. Please ask the researchers if you have any questions about this insurance.

Questions and queries

Should you have any questions about the study please feel free to contact any of the individuals listed below. You are assured that all enquiries will remain confidential.

Name	Title	Contact number	Email address
Inneke Scorgie	Researcher	072 999 3376 / +41 79 715 3251	innekescorgie@gmail.com
Dr Theresa Burgess	Supervisor	021 406 6171	theresa.burgess@uct.ac.za
Dr Romy Parker	Co-Supervisor	021 406 6431	Romy.Parker@uct.ac.za

Please contact the Faculty of Health Sciences Human Research Ethics Committee in case you have any questions or concerns about your rights or welfare as a research participant.

Faculty of Health Sciences Human Research Ethics Committee:

Name	Title	Contact number	Email address
Prof Marc Blockman	Ethics Committee chairman	021 406 6338	marc.blockman@uct.ac.za

Thanking you in advance for your enthusiasm to support research within the field of Sports Physiotherapy.

Kind Regards

Inneke Scorgie BSc Physiotherapy

Informed assent form: Adolescent participants < 18 years

The epidemiology of injuries in competitive swimming adolescents attending a Johannesburg swim squad

Thank you for considering taking part this study.

Confirmation

I understand that I may ask questions at any time during the study. I also understand that I am free to stop with the study without giving a reason at any time, if I choose to do so. I know that the information collected from the study will remain confidential. I have read this form and the information sheet and understand the point of this study. By signing this form I agree to take part in this research study.

______________________________ ___________________________

Adolescent Signature Date

______________________________ ___________________________

Investigator Signature Date

APPENDIX 6: Information sheet and informed consent form for parents

UNIVERSITY OF CAPE TOWN

Faculty of Health Sciences

Department of Health and Rehabilitation Sciences

Divisions of Communication Sciences and Disorders; Nursing and Midwifery; Occupational Therapy; Physiotherapy; Disability Studies

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Fax: +27 (0) 21 406 6323

The epidemiology of injuries in competitive swimming adolescents attending a Johannesburg swim squad

Dear Parent,

My name is Inneke Scorgie and I am a physiotherapy Master's student, at the University of Cape Town. As part of my degree I am required to conduct a study and have chosen to base it on swimmers. In my study I aim to find out which injuries may present in competitive adolescent swimmers over a six-month period. I will evaluate potential risk factors that may make your child more susceptible to sustaining an injury. This study has been given ethical approval by the Human Research Ethics Committee, Faculty of Health Sciences, University of Cape Town.

Little documented research is available regarding the occurrence of swimming injuries. There is even less information available regarding swimming injuries in adolescents (under 18 years of age). This is unfortunate since minors partake in similar strict and rigorous training programs as adults. I would like to add to the knowledge in this field and request your assistance in doing so.

Should you allow your child to take part in the study it would include the following:

- The study aims to collect information from swimmers about their injuries throughout a six-month period from October 2014 – April 2015.
- Only swimmers aged 12 to 18 may take part in the study.
- I will need to do once-off testing of your child, which will take approximately one hour (this will be done in the Virgin Active). I will have volunteers helping me to ensure the process runs smoothly and to maximise time. Four swimmers will be tested at the same time at different stations.
    - We hope to arrange an information evening before we start testing to answer any questions you or your children may have.

    - Testing will occur over a one-week period and I will draw up a roster together with the coach so that each child gets a turn during swim training so as not to inconvenience you.
    - Testing will entail the following:
        - Verbally answering a questionnaire about demographics, injury and training history.
        - Testing shoulder and knee muscle strength
        - Testing movement at the shoulder joint
        - Testing for general joint mobility
        - Recording of 100 meter time trial times during the study period
- After testing your children will need to complete a weekly electronic survey online (much like their school homework diary) about their injury status and weekly training.
    - In this they will be asked questions like:
        - How much, how long, how far they swam that week?
        - How difficult the training sessions were?
        - Do they have an injury and details regarding this?
        - Did they play any other sport in the week?
        - Did they have any treatment for it?

I will send out weekly announcements via the electronic link to remind your children to complete the forms. If your child forgets to send me the relevant data, I will first send out SMS reminders then contact you/them telephonically if I have not received information within 3 days.

If at any stage, your child is not comfortable with the process he/she may withdraw from the study at any time without needing to give any reason.

Privacy and confidentiality

All of the information gained during testing will remain confidential and be shared only with yourselves and your children. You both may then choose whether to disclose the information to the coach. The information gathered will be stored in a secure database, password protected and only I will have access to it. Should the study information be published, participants will remain anonymous.

Anticipated benefits

By doing screening tests we can detect asymmetries, potential muscle imbalances and 'weak spots' to reduce the risk of injuries. This could also help with correction of stroke for those prone to injury. In the long-term this may reduce time spent away from practice and competition because fewer injuries are sustained. If any abnormalities are detected, I will refer your child to an appropriate health care professional for further management.

Possible risks

Some of the tests performed are physical strength tests so your child may experience muscle stiffness afterwards. This is not dangerous and will be minimised by ensuring they warm-up properly beforehand with their coach. Each test will be properly explained to your child until he/she understands what is expected. Demonstrations will be given and pictures shown if need be. They will be allowed to ask questions in the testing process if unsure of procedure.

There are no potential risks associated with online injury reporting and completion of the injury questionnaire.

What if something goes wrong?

The University of Cape Town (UCT) has insurance cover for the event that research-related injury or harm results from your participation in the trial. The insurer will pay all reasonable medical expenses in accordance with the South African Good Clinical Practice Guidelines (DoH 2006), based on the Association of the British Pharmaceutical Industry Guidelines (ABPI) in the event of an injury or side effect resulting directly from your participation in the trial. You will not be required to prove fault on the part of the University. The University will not be liable for any loss, injuries and/or harm that you may sustain where the loss is caused by:

- The use of unauthorised medicine or substances during the study.
- Any injury that results from you not following the protocol requirements or the instructions that the study doctor may give you.
- An injury that results from negligence on your part.

By agreeing to participate in this study, you do not give up your right to claim compensation for injury where you can prove negligence, in separate litigation. In particular, your right to pursue such a claim in a South African court in terms of South African law must be ensured. Note, however, that you will usually be requested to accept that payment made by the University under the SA GCP guideline 4.11 is in full settlement of the claim relating to the medical expenses.

An injury is considered trial-related if, and to the extent that, it is caused by study activities. You must notify the study doctor immediately of any side effects and/or injuries during the trial, whether they are research-related or other related complications.

UCT reserves the right not to provide compensation if, and to the extent that, your injury came about because you chose not to follow the instructions that you were given while you were taking part in the study. Your right in law to claim compensation for injury where you prove negligence is not affected. Copies of these guidelines are available on request.

Questions and queries

Should you have any questions about the study please feel free to contact any of the individuals listed below. You are assured that all enquiries will remain confidential.

Name	Title	Contact number	Email address
Inneke Scorgie	Researcher	072 999 3376 / +41 79 715 3251	innekescorgie@gmail.com
Dr Theresa Burgess	Supervisor	021 406 6171	theresa.burgess@uct.ac.za
Dr Romy Parker	Co-Supervisor	021 406 6431	Romy.Parker@uct.ac.za

You may also contact the Faculty of Health Sciences Human Research Ethics Committee in case you have any questions or concerns about your child's rights or welfare as a research participant.

Faculty of Health Sciences Human Research Ethics Committee:

Name	Title	Contact number	Email address
Prof Marc Blockman	Ethics Committee chairman	021 406 6338	marc.blockman@uct.ac.za

Thanking you in advance for your enthusiasm to support research within the field of Sports Physiotherapy.

Kind Regards,

Inneke Scorgie

Bsc. Physiotherapy (WITS)

Consent form for parents

Thank you for considering your child's participation in this study.

Confirmation

I understand that I may ask questions at any time during the study. I acknowledge that my child is free to withdraw from the study without prejudice at any time, should he/she choose to do so. I understand that the information derived from the research will remain anonymous and confidential. I have read this form and the information sheet and understand the nature, purpose and procedure of this study. I agree for my child to participate in this research study. By signing this document, I accept the above statement and give permission for my child to participate in this study.

______________________________	___________________________
Parent/Legal Guardian Signature	Date
______________________________	___________________________
Investigator Signature	Date

APPENDIX 7: Baseline questionnaire

Name: ___________________________

Date: ____________________________

Except where shown please use a tick [✓] to answer the following questions.

Section A: Demographic Profile

To be filled in by tester
Height: [___________cm]
Weight: [___________ kg]

I am: [ ] left-handed
[ ] right-handed
[ ] both
I write with my: [ ] left hand
[ ] right hand
I throw a ball: [ ] left hand
[ ] right hand

1.I have been swimming for:
[__________years]

2.I started competitive swimming at age:
[__________years]

When I swim I breathe on the:
[ ] left side
[ ] right side
[ ] both sides

Section B: Competition Profile

3. My most preferred strokes in rank order are…
[ ] Free [ ] Fly [ ] Back [ ] Breast [ ] IM

(Example: 1 for most preferred, 2 for second preferred and so on. Use same number for equally preferred strokes)

4. At **Major Competitions** I compete in:
(may tick more than one box if applicable)
[ ] sprint races (50meters, 100 m)
[ ] middle distance (200m, 400m)
[ ] long distance (800m, 1500m)

5. At Major Competitions I swim:
(may tick more than one)
[ ] Freestyle
[ ] Butterfly
[ ] Backstroke
[ ] Breaststroke
[ ] IM

6. In the past 12 months my personal best (PB) times for my top five events are:
1) Event:___________PB___________(min/sec)
2) Event:___________PB___________(min/sec)
3) Event:___________PB___________(min/sec)
4) Event:___________PB___________(min/sec)
5) Event:___________PB___________(min/sec)

7. Before this study my highest level of competition in swimming was:
[ ] international [ ] national [ ] provincial [ ] regional [ ] club

Please write your best swimming achievement until now:
____

Section C: Training Profile (over the last 12 months)

8. The average distance I swim per km per week is:
[____ km] I don't know [ ]

9. The average distance that I swim per session is:
[____ km] I don't know [ ]

10. The number of pool sessions that I train per week is:
[___________sessions]

11. In training, I spend this percent of time doing these strokes: *(must equal 100% together)*

Free	Fly	Back	Breast
[%]	[%]	[%]	[%]

12. I regularly include stretching exercises in my training for swimming:
[ ] Yes [ ] No

13. Someone else regularly stretches me:
[ ] Yes [ ] No

14. I would use hand paddles this number of times per week:
[ ] none [ ] 1-2 [ ] 3-4 [ ] >5

15a) The number of land sessions I do per week:
[______________sessions] *(eg 0 = no sessions)*

b) During land-training I spent this percentage:

Bodyweight	Weights	Stretch cords	other*
[%]	[%]	[%]	[%]

If *other please write: ____________________

Section D: Injury Profile (over the last 12 months)	
Part 1	**Part 2**
15. Over the past 12 months, I have…. *(tick one option only)* [ ] a) Never suffered from any pain or discomfort related to a swimming injury [ ] b) Felt pain or discomfort but the pain has not caused me to stop or change my training [ ] c) Felt pain or discomfort while swimming which did not cause me to stop or change my training, but the pain continued after finishing the training session [ ] d) Felt the pain while swimming which caused me to change my training, but did not cause me to stop training completely [ ] e) Felt pain while swimming which caused me to stop training for less than 4 sessions [ ] f) Felt pain which has caused me to miss 5 or more swimming sessions or a competition 16. The injured body area(s) was/were the: *(may tick more than one)* [ ] Foot & ankle [ ] Knee [ ] Hip [ ] Back [ ] Neck [ ] Shoulder [ ] Elbow [ ] Wrist [ ] **Other please write*:_______________ 17. The injured area was on the: [ ] Left [ ] Right [ ] Both 18. To prevent any injuries I visit: [ ]Masseur [ ]Physio [ ]Chiropracter [ ]No one [ ] **other Please write:* _______________ 19. I have musculoskeletal screening: [ ] once per year [ ]twice per year [ ] never [ ] other _____________________	**SKIP this question** if you have <u>not</u> **had any injury pain** in the **last 12 months** Please think of the worst episode injury you experienced over the past 12 months. For this period of pain, identify up to three important activities that you were unable to do, or had difficulty doing because of the injury. For each activity that you identify, please give a score from 0 to 10, depending how much difficulty you had with it. You may list additional activities. **ACTIVITY SCORING SCHEME:** **0 1 2 3 4 5 6 7 8 9 10** Unable Able to perform activity at same level as before injury / problem In the past 12 months, were there any activities that you were unable to do or had difficulty with because of your injury? (please list and score below). *You <u>must</u> complete for freestyle pull, and recovery.* *(e.g Freestyle pull 1/10, dressing 7/10, remember 0= unable to do it!!)* Activity 1 Freestyle Pull Score................../10 2 Freestyle Recovery Score.................../10 3 _________________ Score.................../10 4__________________ Score.................../10 5_________________ Score.................../10
Part 3	
Current body pain: **Please tick only the most appropriate category which describes how your injured area is feeling today:** [ ] a) None: No pain today. [ ] b) Significant Interfering Injury Pain, which is pain that <u>interferes</u> with effective or quality training or competition, or your progress in training. It causes you to <u>stop or change your training</u> or racing in some way. [ ] c) Non-significant injury pain and Normal soreness, which is pain that is usually described as a niggle. It is definitely pain, but <u>does not</u> interfere with your ability to train or compete effectively. It <u>does not</u> cause you to stop or change your training or racing. **Normal soreness* is the normal muscle soreness you get from heavy or vigorous training. It does not interfere with training or racing.	

APPENDIX 8: Modified Borg scale

RPE scale	
Numeric rating	**Perceived exertion**
0	Rest
1	Really easy
2	Easy
3	Moderate
4	Sort of hard
5	Hard
6	
7	Really hard
8	
9	Really, really hard
10	Maximal, just like your hardest race

APPENDIX 9: Information sheet for coaches of Waterborn

UNIVERSITY OF CAPE TOWN

Faculty of Health Sciences

Department of Health and Rehabilitation Sciences

Divisions of Communication Sciences and Disorders; Nursing and Midwifery; Occupational Therapy; Physiotherapy; Disability Studies

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Fax: +27 (0) 21 406 6323

The epidemiology of injuries in competitive swimming adolescents attending a Johannesburg swim squad

Dear Peter Williams (Club Director),

Cc: Phillipe van der Leeuw (Coach)

Request permission to perform a study on swimmers of Waterborn swim club aged 12 - 18

I am a Masters in Sports Physiotherapy student, at the University of Cape Town, Division of Physiotherapy. As part of my degree I am required to conduct a study and have chosen to base it on swimmers. I aim to find out which injuries present in competitive adolescent swimmers over a six-month period. I will evaluate potential factors that may make a swimmer more susceptible to sustaining an injury. This study has been granted ethical approval by the University of Cape Town, Faculty of Health Sciences Human Research Ethics Committee.

Little documented research is available regarding occurrence of swimming injuries. There is even less information available regarding swimming injuries in adolescents (under 18 years of age). This is unfortunate since minors partake in similar strict and rigorous training programs as adults. Therefore, I would like to request your permission to perform my study on members of your squad, to increase the knowledge of adolescent swimming injuries.

Following is a rough outline of what I plan to do and we can discuss the details in person.

- The study aims to follow swimmers throughout a six-month period from October 2014 to April 2015.

- I will need to do once-off testing which will take approximately one hour per swimmer (this will hopefully be done in a private room of the Randburg Virgin Active as needs to be discussed with the gym club manager). Screening will occur within a one - two week period and I will draw up a roster together with you. Ideally, we would like to screen four participants at the same time. I will have physiotherapy students assisting with data collection. If possible, I would like to evaluate adolescents during their swim training time so as not to inconvenience parents, participants and yourselves.
- Once-off screening will include:
    - Injury history and training profile questionnaire
    - Measurement of shoulder range of movement
    - Measurement of shoulder and knee muscle strength
    - Measurement of joint mobility

- The swimmers will need to keep an electronic training and injury logbook (much like their school homework diary, except that it has the convenience of being on their cell phone or pc). They then need to forward to me the data via email, fax or whatssapp during the course of the week. For those who don't have access to electronic devices, hard copies in paper format can be arranged.

- It may be required that I check in weekly with you over the six month period via email / whatsapp / IM or any method you prefer to determine whether anyone has sustained any injuries within the week. It would be very helpful if you could then also give me details of estimated weekly training volumes for the different groups if I am unable to ascertain this information from the swimmers' feedback..

- I request that I may have the results of each participant's 100 meter freestyle sprint time trial in the months of October, December and April.

Potential benefits to the swimmers

By doing screening tests we can detect asymmetries, potential muscle imbalances and 'weak spots' to reduce the risk of injuries. This could also help with correction of stroke for those prone to injury. In the long term this reduces time spent away from practice and competition because fewer injuries are sustained. Risk factors can then be addressed going forward by attending a rehabilitation programme if necessary.

Questions and Queries

Should you have any questions about the study please feel free to contact any of the individuals listed below. You are assured that all enquiries will remain confidential.

Name	Title	Contact number	Email address
Inneke Scorgie	Researcher	072 999 3376 / +41 797 153 251	innekescorgie@gmail.com
Dr Theresa Burgess	Supervisor	021 406 6171	theresa.burgess@uct.ac.za
Romy Parker	Co-Supervisor	021 406 6431	Romy.Parker@uct.ac.za

You may also contact the Faculty of Health Science Human Research Ethics Committee in case you have any questions or concerns about.

Faculty of Health Sciences Human Research Ethics Committee:

Name	Title	Contact number	Email address
Prof Marc Blockman	Ethics Committee chairman	021 406 6338	marc.blockman@uct.ac.za

Thanking you in advance for your enthusiasm to support research within the field of Sports Physiotherapy.

Kind Regards

Inneke Scorgie

Bsc. Physiotherapy (WITS)

APPENDIX 10: Information sheet and consent form for research assistants

UNIVERSITY OF CAPE TOWN

Faculty of Health Sciences

Department of Health and Rehabilitation Sciences

Divisions of Communication Sciences and Disorders; Nursing and Midwifery; Occupational Therapy; Physiotherapy; Disability Studies

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Fax: +27 (0) 21 406 6323

Information sheet volunteers

The epidemiology of injuries in competitive swimming adolescents attending a Johannesburg swim squad

Dear Volunteers,

My name is Inneke Scorgie and I am a physiotherapy Master's student, at the University of Cape Town. As part of my degree I am required to conduct a study and have chosen to base it on swimmers. In my study I aim to determine the relationship between injuries in adolescent swimmers and the factors which potentially cause them. This study has been given ethical approval by the Human Research Ethics Committee, Faculty of Health Sciences, University of Cape Town.

Little documented research is available regarding the occurrence of swimming injuries. There is even less information available regarding swimming injuries in adolescents (under 18 years of age). This is unfortunate since minors partake in similar strict and rigorous training programs as adults. I would like to add to the knowledge in this field and request your assistance in doing so.

I the assistance I require includes data collection as the study involves screening approximately 30 swimmers.

Assessment of each adolescent is estimated to take one hour. Your assistance may entail aspects of the following:

- Measurement of knee and shoulder muscle strength using a hand held dynamometer
- Administration of the Beighton Score using quick tests
- Administration of a demographic questionnaire
- Measurement of shoulder range of motion using a goniometer
- Collecting anthropometric measures like weight and height.

<u>Date, time and place</u>

Data collection will take place next week from the 27th – 31st October. I aim to screen the swimmers before and after their afternoon swim sessions. This means I require assistance from 3:30pm – 8:30pm each day for the complete four hours. Screening will take place in the Virgin Active Randburg, corner Hans Schoeman and Malibongwe Street. Should you have a Virgin Active membership with access card please bring this along to facilitate entry to the premises. If not, please liase with me prior to the time so I can arrange access with management.

<u>Remuneration</u>

Per day you would receive R250 for your assistance with data collection (R50 / hour).

<u>Procedure</u>

I require four volunteers per day. Four swimmers will be assessed simultaneously at stations (A – D), thus I will need a minimum of one person to man each station (i.e. 4 people including myself). The forth volunteer will be asked to take anthropometric measures (weight and height) and scribe muscle strength measurements. You will receive step-by-step instructions on how to assess the adolescents. You will be given an instruction sheet together with pictures and a short demo. To facilitate this, please arrive 15 minutes earlier if possible. I will co-ordinate one of the stations and am available for questions at any time. You will then explain the same set of instructions to the swimmer and administer the tool. The four stations will rotate after an approximate 15 minutes so as to facilitate rapid turnover and smooth coordination.

What to wear

As long as you are comfortable and presentable I don't mind what you wear. Preferable would be navy / black pants and white top but it is really up to you.

Questions and queries

Please feel me to contact me should you have any queries regarding the study.

Name	**Contact number**	**Email address**
Inneke Scorgie	072 999 3376	innekescorgie@gmail.com / innekeadelfang@yahoo.com

I would be extremely grateful for any help on one or more days of data collection. Please contact me directly should you be able to assist. Thanking you in advance for your enthusiasm to support research within the field of Sports Physiotherapy.

Kind Regards

Inneke Scorgie

Bsc. Physiotherapy (WITS)

UNIVERSITY OF CAPE TOWN

Faculty of Health Sciences

Department of Health and Rehabilitation Sciences
Divisions of Communication Sciences and Disorders; Nursing and Midwifery; Occupational Therapy; Physiotherapy; Disability Studies

F45 Old Main Building, Groote Schuur Hospital
Observatory, Cape Town, W Cape, 7925
Tel: +27 (0) 21 406 6401/ 6428/ 6628/ 6534
Fax: +27 (0) 21 406 6323

Consent form for volunteers

The epidemiology of injuries in competitive swimming adolescents attending a Johannesburg swim squad

Thank you for assisting with data collection in this study.

Confirmation

I have read the information sheet and understand the purpose of the study. I understand that the data collected from the study must remain confidential and anonymous at all times. I undertake to provide screening in a safe and studious manner so as to prevent undue harm to both study participants and myself. By signing this form I agree to assist with data collection in this research study and accept all of the above.

______________________ ______________________ ______________

Volunteer name Volunteer signature Date

Questions and queries

Should you have any questions about the study please feel free to contact any of the individuals listed below. You are assured that all enquiries will remain confidential. The university reserves the right to a *No faults insurance*.

Name	**Title**	**Contact number**	**Email address**
Inneke Scorgie	Researcher	072 999 3376	innekescorgie@gmail.com
Dr Theresa Burgess	Supervisor	021 406 6171	theresa.burgess@uct.ac.za
Romy Parker	Co-Supervisor	021 406 6431	Romy.Parker@uct.ac.za

Please contact the Faculty of Health Sciences Human Research Ethics Committee in case you have any questions or concerns about your rights or welfare as a research volunteer.

Faculty of Health Sciences Human Research Ethics Committee:

Name	**Title**	**Contact number**	**Email address**
Prof Marc Blockman	Ethics Committee chairman	021 406 6338	marc.blockman@uct.ac.za

Thanking you in advance for your enthusiasm to support research within the field of Sports Physiotherapy.

Kind Regards

Inneke Scorgie BSc Physiotherapy (WITS)

APPENDIX 11: Ethics approval

UNIVERSITY OF CAPE TOWN
Faculty of Health Sciences
Human Research Ethics Committee

Room E52-24 Old Main Building
Groote Schuur Hospital
Observatory 7925
Telephone [021] 404 7682 • **Facsimile** [021] 406 6411
Email: nosi.tsama@uct.ac.za
Website: www.health.uct.ac.za/research/humanethics/forms

21 October 2014

HREC REF: 768/2014

Dr T Burgess
Division of Physiotherapy
Health & Rehabilitation Sciences
F45, Old Main Building

Dear Dr Burgess

PROJECT TITLE: THE EPIDEMIOLOGY OF INJURIES IN COMPETITIVE SWIMMING ADOLESCENTS ATTENDING A JOHANNESBURG SWIM SQUADRON - Mphil candidate- Inneke Scorgie)

Thank you for submitting your study to the Faculty of Health Sciences Human Research Ethics Committee for review.

It is a pleasure to inform you that the HREC has **formally approved** the above-mentioned study.

Approval is granted for one year until the 30th October 2015.

Please submit a progress form, using the standardised Annual Report Form if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.
(Forms can be found on **our website: www.health.uct.ac.za/research/humanethics/forms**)

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

We acknowledge that the MPhil student, Inneke Scorgie is also involved in this study.

Please quote the HREC reference no in all your correspondence.

Yours sincerely

PROFESSOR M BLOCKMAN
CHAIRPERSON, FHS HUMAN ETHICS
Federal Wide Assurance Number: FWA00001637.
Institutional Review Board (IRB) number: IRB00001938
This serves to confirm that the University of Cape Town Human Research Ethics Committee complies to the Ethics Standards for Clinical Research with a new drug in patients, based on the Medical Research Council (MRC-SA), Food and Drug Administration (FDA-USA), International Convention on Harmonisation Good Clinical Practice (ICH GCP) and Declaration of Helsinki guidelines.
The Human Research Ethics Committee granting this approval is in compliance with the ICH Harmonised Tripartite Guidelines E6: Note for Guidance on Good Clinical Practice (CPMP/ICH/135/95) and FDA Code Federal Regulation Part 50, 56 and 312.

UNIVERSITY OF CAPE TOWN

FACULTY OF HEALTH SCIENCES
Human Research Ethics Committee

FHS016: Annual Progress Report / Renewal

HREC office use only (FWA00001637; IRB00001938)						
This serves as notification of annual approval, including any documentation described below.						
☑ Approved	Annual progress report	Approved until/next renewal date		28	02	2017
☐ Not approved	See attached comments					
Signature Charperson of the HREC			Date Signed	10/2/16		

Comments to PI from the HREC

Principal Investigator to complete the following:

1. Protocol Information

Date (when submitting this form)	8th February 2016		
HREC REF Number	768/2014	Current Ethics Approval was granted until	30TH October 2016
Protocol title	THE EPIDEMIOLOGY OF INJURIES IN COMPETITIVE SWIMMING ADOLESCENTS ATTENDING A JOHANNESBURG SWIM SQUADRON		
Protocol number (if applicable)	N/A		
Are there any sub-studies linked to this study?	☐ Yes	X No	
If yes, could you please provide the HREC Ref's for all sub-studies? **Note:** A separate FHS016 must be submitted for each sub-study	N/A		
Principal Investigator	Theresa Burgess		
Department / Office Internal Mail Address	Department of Health and Rehabilitation Sciences, F45 Old Main Building, Groote Schuur Hospital		

RESEARCH ETHICS COMMITTEE
2016 -02- 09
HEALTH SCIENCES FACULTY
UNIVERSITY OF CAPE TOWN

1.1 Does this protocol receive US Federal funding?	☐ Yes	X No
1.2 If the study receives US Federal Funding, does the annual report require full committee approval?	☐ Yes	X No
1.3 Has sponsorship of this study changed? If yes, please attach a revised summary of the budget.	☐ Yes	X No

(Note: Please complete the Closure form (FHS010) if the study is completed within the approval period)

UNIVERSITY OF CAPE TOWN

FACULTY OF HEALTH SCIENCES
Human Research Ethics Committee

09 FEB 2016

Form FHS011: Study deviation

HREC office use only (FWA00001637; IRB00001938)			
This serves as acknowledgement of a protocol deviation as described below			
Chairperson of the HREC signature		Date	14/2/2016

Principal Investigator to complete the following:

1. Protocol information

Date (when submitting this form)	8th February 2016
HREC REF Number	HREC REF 768/2014
Project Title	THE EPIDEMIOLOGY OF INJURIES IN COMPETITIVE SWIMMING ADOLESCENTS ATTENDING A JOHANNESBURG SWIM SQUADRON
Protocol number (if applicable)	N/A
Principal Investigator	Theresa Burgess
Department / Office Internal Mail Address	Department of Health and Rehabilitation Sciences, F45 Old Main Building, Groote Schuur Hospital

2. Protocol deviation description

Please describe the deviation below, including the reason why the deviation occurred.
Annual approval for this study expired on 30th October 2015. I am therefore requesting late approval of this research project. This is a master's student research project. All data collection was completed by June 2015. During data analysis, the student relocated with her family to live overseas and had a baby, and the completion of her dissertation (intended for August 2015) was delayed. As PI, I neglected to obtain annual approval timeously and apologise for this oversight.

3. Follow-up actions

3.1 Please describe any follow-up action(s) taken or planned as a result of this deviation e.g. DSMB reporting, report to sponsor, informing participants
None required. Data collection had been completed well before annual approval expired.
3.2 Please describe what action(s) have or will be taken to prevent similar deviations in future
I am reviewing all of my outstanding postgraduate student research projects to ensure that all are up to date. The Department has also appointed an administrative assistant to assist with research project administration.

APPENDIX 12: ADDITIONAL RESULTS

Table 10.1: Summary of competitions per week in uninjured and injured groups. Data are expressed as numbers (n).

Competition (n)	Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Total
	uninjured group	1	0	0	3	0	3	0	1	3	3	3	8	14	9	7	2	8	0	0	0	0	5	0	0	70
	injured group	0	2	0	4	4	11	1	0	2	7	8	10	19	13	8	1	11	5	0	2	1	8	0	0	117

Table 10.2: Summary of dry-land sessions per week in uninjured and injured groups. Data are expressed as numbers (n).

Dry-land sessions (n)	Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
	uninjured	12	13	5	3	4	1	0	17	9	8	8	9	7	3	4	2	2	2	2	4	1	3
	injured	20	15	20	11	5	9	7	13	16	18	15	12	12	6	8	4	4	5	12	10	13	7
	Total	32	28	25	14	9	10	7	30	25	26	23	21	19	9	12	6	6	7	14	14	14	10
	Average per participant	1.4	1.2	1.1	0.6	0.4	0.3	0.3	1.4	1.1	1.2	1.1	1	0.9	0.4	0.6	0.3	0.3	0.4	0.8	0.8	0.8	0.6

Table 10.3: Summary of self-reported injury type. Data are expressed as numbers (n) and percentages (%).

Injury type	Muscle	Don't know	Cartilage	Joint	Tendon	Bone	Nerve	Ligament
n (%)	23 (38)	13 (22)	9 (15)	7 (11)	4 (7)	2 (3)	1 (2)	1 (2)

Table 10.4: Summary of factors aggravating pain during swimming. Data are expressed as numbers (n) and percentages (%).

Activity aggravating pain while swimming	Pull buoy	Paddles	Kickboards	Nothing	Drills	Time trials
(n)	19	15	15	5	3	2

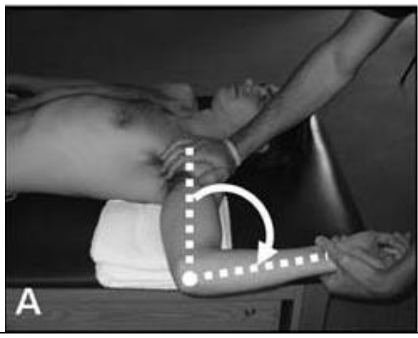
Table 10.5: Summary of swimming training sessions modified or missed due to injury. Data are expressed as numbers (n).

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Total
Swim sessions modified (n)	0	5	0	9	1	0	0	0	2	2	0	0	1	1	0	0	0	0	0	0	0	1	0	0	22
Swim sessions missed (n)	8	0	0	0	0	0	0	0	5	5	0	9	1	1	0	0	0	0	0	0	0	1	0	0	30

APPENDIX 13: Data collection information sheets for assistants

Information Sheet: Shoulder rotation measurement

1) Explain to swimmer that you will measure their passive shoulder rotation whilst lying supine, forearm perpendicular to the floor
2) Mark olecranon and styloid processes with felt-tipped pens
3) Always measure **LEFT side first** (only the tester performs the movement)
4) Apply pressure to anterior shoulder to stabilise scapula; stop measurement before point of scapula rotation (shoulder lifting)
5) Document findings in data collection sheet

Tested movement	**Starting position**	**End position**	**Goniometer position**
Internal rotation	• Supine on plinth • 90° shoulder abduction, 90° elbow flexion, arm in body plane • Starting position 0° with forearm perpendicular to floor • Downward pressure applied to anterior shoulder to stabilize scapula	Tester internally rotates arm only until posterior scapula rotation occurs 	**Stationary arm:** perpendicular to the table **Mobile arm:** in alignment with forearm starting at olecranon and pointing at ulnar styloid process **Fulcrum:** over olecranon process
External rotation	• Supine on plinth • 90° shoulder abduction, 90° elbow flexion, arm in body plane • Starting position 0° with forearm perpendicular to floor • Pressure applied to anterior shoulder to stabilize scapula	Tester maximally externally rotates arm 	**Stationary arm:** perpendicular to the table **Mobile arm:** in alignment with forearm starting at olecranon and pointing at ulnar styloid process **Fulcrum:** over olecranon process

Info Sheet: Shoulder and Knee strength measurements using hand-held dynamometer

1) Instructions and demonstration given before each movement
2) Mark with felt-tipped pen: 5cm prox to med malleolus (use pre-cut 5cm strip)
3) Participant to work up to maximum voluntary contraction over 1 – 2 seconds
4) Sustain contraction over further 4- 5 seconds
5) Verbal queues of "*go ahead –push-push-push-push and relax*"
6) Two trial runs / familiarisation procedures
7) Four actual measures to be taken and recorded to 1 decimal point
8) 30 seconds rest-period between 4 separate measures

Movement	Starting position	HHD position
Elevation[128]	• **participants seated upright on a chair** with both feet stationed on the floor • upper limb placed in 90° shoulder flexion and 30° horizontal abduction (palm down)	• HHD placed centrally onto dorsal aspect of distal forearm (parallel to ground) • caudad force is exerted through HHD
Hand behind back lift-off[128]	• **participants seated upright on a chair** with both feet stationed on the floor • upper limb placed behind back in the midline (no contact of hand with back)	• HHD placed centrally onto palmar aspect of distal forearm (perpendicular to forearm) • anterior force is exerted through HHD
Horizontal abduction[42,100]	• participant positioned **prone** • upper limb placed in 90° abduction, full elbow extension and wrist in neutral (palm down)	• HHD placed centrally onto dorsal surface of distal forearm (parallel to ground) • downward force exerted through HHD
External rotation[42,100]	• participant positioned **prone** • upper limb in 90° abduction, 0° rotation and elbow flexed to 90° • humerus stabilised distally against plinth	• HHD placed centrally onto dorsal surface of distal forearm (perpendicular to ground) • caudad force is exerted through HHD
Internal rotation[42,100]	• participant positioned **prone** • upper limb in 90° abduction, 0° rotation and elbow flexed to 90° • humerus stabilised distally against plinth	• HHD placed centrally onto palmar surface of distal (perpendicular to ground) • cephalad force is exerted through HHD
Knee Flexion [136,137]	• participants seated at the edge of plinth • hips and knees at 90° flexion, feet hanging free	• HHD placed on posterior aspect of calcaneus (perpendicular to leg) • participant exerts posterior force through HHD
Knee extension [136,137]	• participants seated at the edge of plinth • hips and knees at 90° flexion, feet hanging free	• HHD placed onto anterior aspect of distal tibia, five cm proximal to medial malleolus (perpendicular to leg) • participant exerts anterior force through HHD

<u>**Information Sheet: Beighton Score**</u>

Motion tested	Test position	Goniometer positioning and anatomic landmarks	Method	Positive score if:
Passive dorsiflexion fifth finger	**Sit on chair** at the short side of plinth with arm in 80 degree(°) of abduction, elbow flexed 90°, forearm pronated and resting on the table	Stationary arm: parallel to fifth metacarpal Mobile arm: parallel to fifth digit Pivot: fifth metacarpophalangeal joint 	Lateral	≥90° Equals 1 point (<90° 0 points)
2)Passive hyperextension of the elbow	Sit on chair with shoulder in 90° flexion resting the arm on a towel on plinth, forearm supination	Stationary arm: parallel to humerus pointing to greater tuberosity Mobile arm: parallel to radius pointing at radial styloid process Pivot: lateral humeral epicondyle 	Lateral	≥10° Equals 1 point (<10° 0 points)
3)Passive hyperextension of the knee	Lie supine on plinth. Tester to stabilise femur, whilst holding around malleoli with other hand.	Stationary arm: parallel to femur pointing at greater trochanter Mobile arm: parallel to fibula pointing at lateral malleolus Pivot: Lateral femoral epicondyle 	Lateral	≥10° Equals 1 point (<10° 0 points)

1) Mark fulcrum with felt-tipped pen – 5th MCP jt, lateral humeral epicondyle, lateral femoral epicondyle
2) Participants to passively gently perform items 1 and 4 after demo (Tester measures item 1)
3) Tester performs items 2 and 3 (rest upper arm on towel for elbow measurement)

Motion tested	Test position	Goniometer positioning and anatomic landmarks	Method	Positive score if:
4)Passive apposition of thumb to flexor side of forearm	Shoulder flexed to 90°, elbow extended, forearm pronated	N/A  Score: Positive  Score: Negative	N/A	Whole thumb must touch flexor side of forearm to get 1 point (unable 0 points)
5) Trunk flexion	Standing with feet hip width apart, knees straight, perform forward flexion of trunk and hips	N/A  Score: Positive  Score: Negative	N/A	Hand palms rest easily on the floor get 1 point (unable 0 points)

APPENDIX 14: Data collection sheet per participants

Individual scoring sheet (completed together with tester)

Data Collection Sheet Name: ___________________________

Station 2: Shoulder range of movement measurement

Movement	**ROM (°)**	
	Left	**Right**
GIR		
GER		
TAM		
GIRD		

Key: GIR – glenohumeral internal rotation; GER – glenohumeral external rotation; TAM – total arc of motion deficit; GIRD – glenohumeral internal rotation deficit

Station 3: Muscle strength measurement

Joint	**Movement**	**Strength**							
		Left				**Right**			
		1	2	3	Ave	1	2	3	Ave
Shoulder	Elevation								
	Lift off								
	Horizontal abduction								
	External rotation								
	Internal rotation								
Knee	Flexion								
	Extension								

Station 4: Beighton Score
